Foundation Physics for class X Book 1 for IIT JEE standard 10 by Prof. K K Anand SmartEdu

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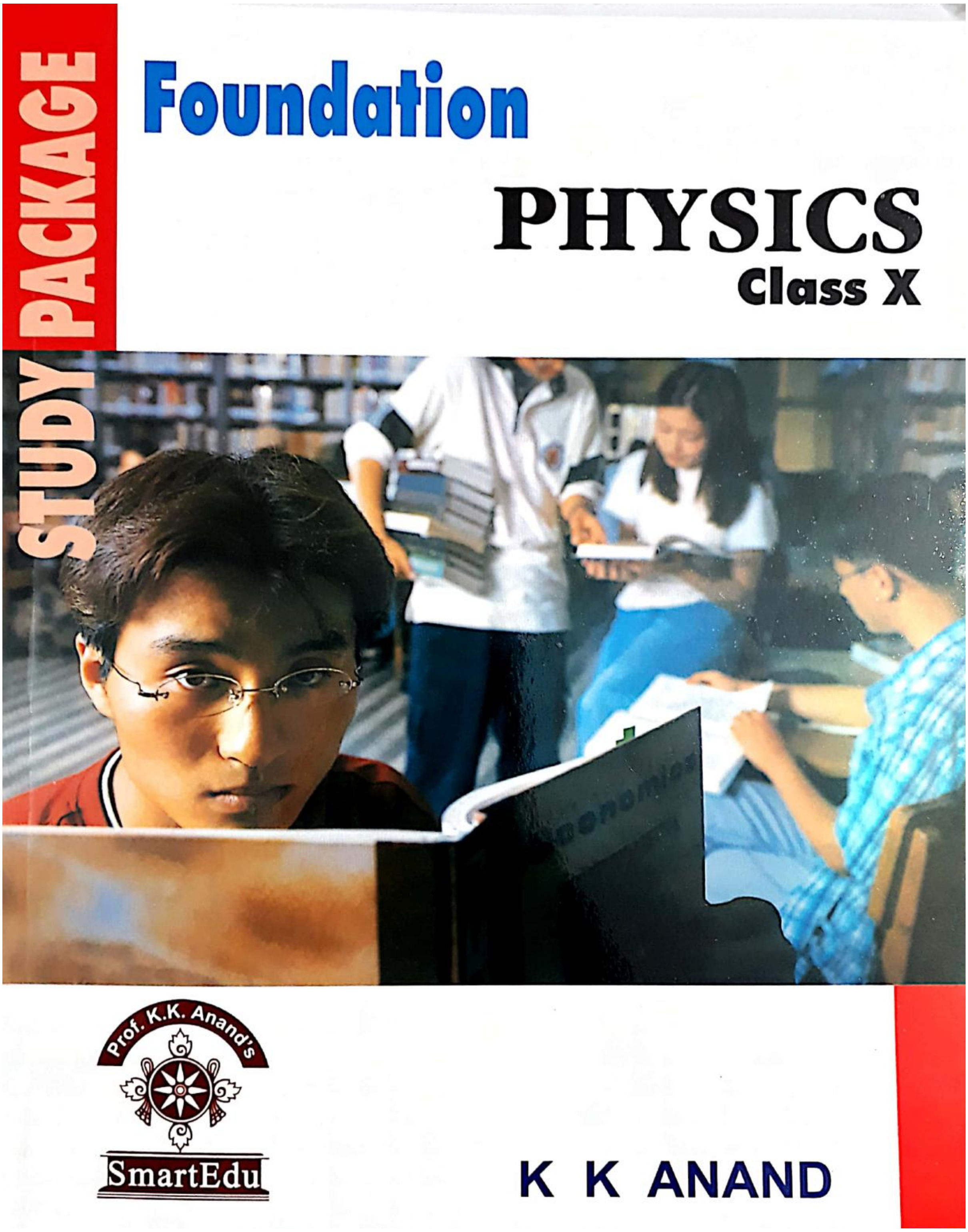
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# STUDY PACKAGE FOUNDATION
# CLASS X

# PHYSICS

## BOOK - 1

CONTENTS



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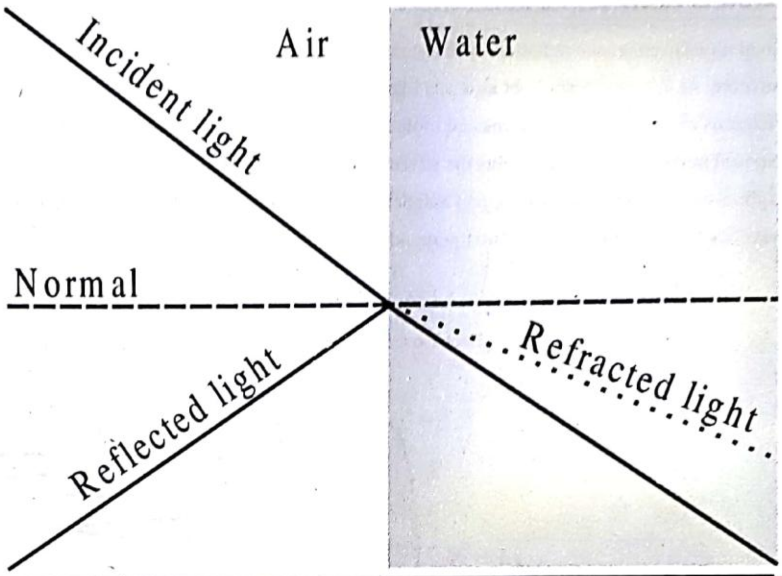
chapter 1




# LIGHT

## Introduction

Light is a form of energy which enables human beings and creatures to 'see' things. When light emitted from an object or reflected from the object enters our eyes we are able to see the object. We can't see an object in dark even if we are in light because there is no light coming from the object to our eyes.

Light is an electromagnetic radiation which exhibits properties like a wave as well as a particle. It always propagates in a straight line and reflects, refracts or shows total internal reflection at an interface separating two media in different conditions. This chapter is an attempt to provide sufficient information to make us understand what is light, how does it propagate, how does it show reflection, refraction and total internal reflection, how does it behave with mirrors and lenses, etc.

## WHAT IS LIGHT ?

Light is electromagnetic radiation, such as that emitted by the Sun, which acts like a wave in a frequency range that the human eye can perceive. At the same time, light also acts like a stream of particles, which are called photons (hence the expression "beam of light"). Electrons can be shot out of atoms and molecules can be split simply by the impact of a photon striking them. A film in a camera is exposed in this way; the light splits the silver bromide into silver and bromine. The silver darkens the film and a negative is created. Light is a combination of electric and magnetic oscillations in mutually perpendicular directions as shown in Fig. 1.1. But the light wave itself propagates in a direction perpendicular to both the oscillations.

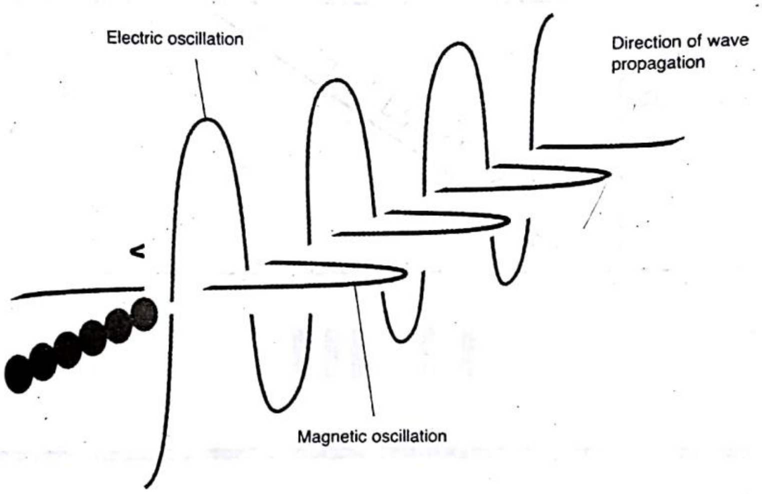
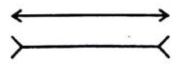
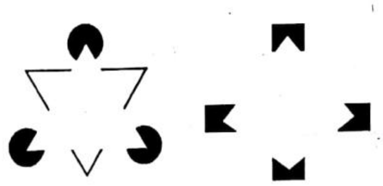



*Fig. 1.1 Electric and magnetic oscillations are mutually perpendicular. The light wave propagates in a direction perpendicular to both.*

*Look at fig. Which line do you think is the longer? Measure the two lines to prove that they are, in fact, equal in length. Why do you think the lower line 'looks' longer than the upper line?*





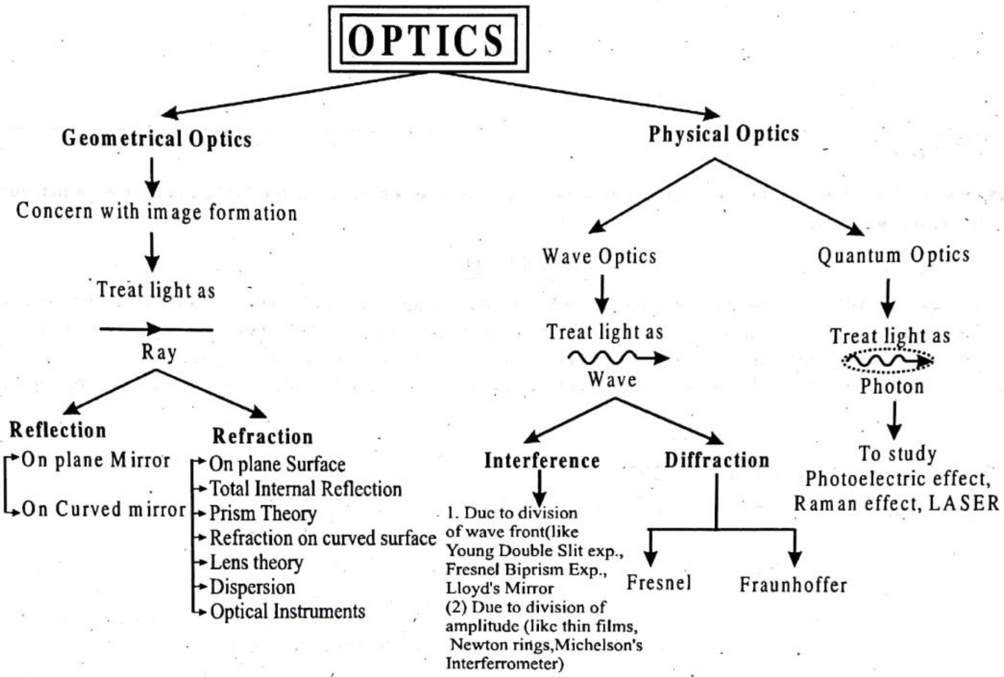
See Pyramid (not drawn) in two figures

**Illusions**

**What do you see ? A candle or two faces ?**

## OPTICS

The branch of physics which deals with the propagation, nature and behaviour of light is known as optics. The different branches of optics and the behaviour of light falling under that branch can best be illustrated by the following diagram.




## PROPERTIES OF LIGHT

(1) Light travels along a straight line in a medium or vacuum. The path of light changes only when the medium changes. This is also called the rectilinear propagation of light.

(2) Light travels with a speed nearly equal to $3 \times 10^8$ m/s. According to current theories, no material particle can travel at a speed greater than the speed of light.

(3) Light shows different behaviour such as reflection, refraction, interference, diffraction, polarisation etc. some of which we will deal with subsequently in this book and some in higher classes.

## RAY OF LIGHT

Let us consider a source of light(s). Also consider the light which passes from the point A to the point B in a medium. Actually, the light passes through all the points of the straight line AB. Such a straight line path is called a ray of light, generally represented by a directed arrow (→).

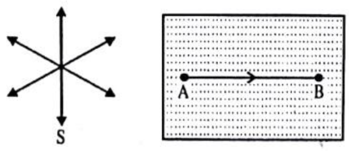



*Fig. 1.2 AB is a ray of light in a medium*

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## BEAM OF LIGHT

A bundle of light rays is called a beam of light. The following figure shows a parallel beam of light.

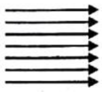


*Fig. 1.3 A parallel beam of light.*

## CHECK Point

**A person in a dark room looking through a window can clearly see a person outside in the daylight, whereas the person outside cannot see the person inside. Explain.**

**SOLUTION**

When a person inside a darkroom is looking through a window to another person outside in broad daylight, then enough reflected rays come inside to the eye of the observer from the person outside. So he can be seen clearly. But if the person in daylight, looks through the same window to the person inside the dark room, there is hardly any reflected rays coming from the body of the person inside the dark room to the eyes of the observer outside. So the outside observer can't see the person inside the room.

## REFLECTION AND REFRACTION OF LIGHT

Most of the things we see around us do not emit their own light. They are visible because they reemit light reaching their surface from a primary source, such as the sun or a lamp, or from a secondary source, such as the illuminated sky. When light falls on the surface of a material, it is usually either reemitted without change in frequency or is absorbed into the material and turned into heat. Usually, both of these processes occur in varying, degrees. When the reemitted light is returned into the medium from which it came, it is *reflected*, and the process is referred to as **reflection**. When the reemitted light bends from its original course and proceeds in straight lines from molecule to molecule into a transparent material, it is *refracted*, and the process is referred to as **refraction**.

## REFLECTION

When this page is illuminated by sunlight or lamplight, electrons in the atoms of the paper vibrate more energetically in response to the oscillating electric fields of the illuminating light. The energized electrons reemit the light by which we see the page. When the page is illuminated by white light, it appears white, which reveals the fact that the electrons reemit all the visible frequencies. Very little absorption occurs. The ink on the page is a different story. Except for a bit of reflection, the ink absorbs all the visible frequencies and therefore appears black. The following figure shows reflection of a building in the sea.

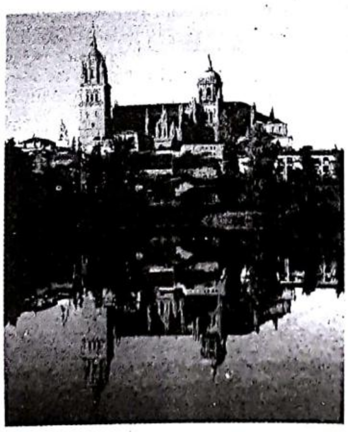


*Fig. 1.4 Image of a building in the sea due to reflection of light*

## LAWS OF REFLECTION

Anyone who has played pool or billiards knows that, when a ball bounces from a surface, the angle of incidence is equal to the angle of rebound. The same is true of light. This is the law of **reflection**, and it holds for all angles:

**The angle of reflection equals the angle of incidence.**

The law of reflection is illustrated with arrows representing light rays in Fig. 1.5 Instead of measuring the angles of incident and reflected rays from the reflecting surface, it is customary to measure them from a line perpendicular to the plane of the reflecting surface. This imaginary line is called the normal. The incident ray, the normal, and the reflected ray all lie in the same plane.

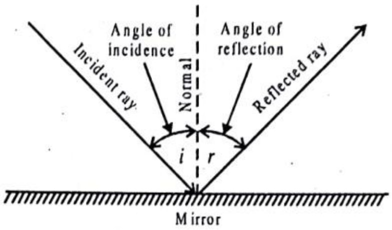


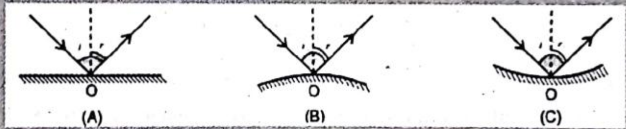

*Fig.1.5 According to the law of reflection i = r. The incident ray, the reflected ray, and the normal all lie in the same plane.*

So, we can summarise the laws of reflection as below :

1. The angle of incidence ($i$) is always equal to the angle of reflection ($r$), i.e., $i = r$.
2. The incident ray, the normal, and the reflected ray all lie in the same plane.

## Knowledge ENHANCER

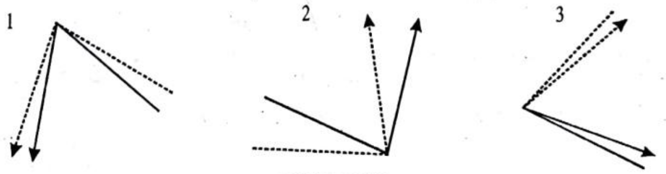
1. Laws of reflection are applicable for plane surfaces as well as curved surfaces.




2. Most people are surprised by the fact that light can be reflected back from a less dense medium. For instance, if you are diving and you look up at the surface of the water, you will see a reflection of yourself.

## CHECK Point

- **Each of these diagrams numbered 1, 2 and 3 is supposed to show two different rays being reflected from the same point on the same mirror. Which are correct, and which are incorrect ?**




**SOLUTION**

Only 1 is correct. Draw the normal that bisects the solid ray, it also bisects the dashed ray.

## SPECULAR AND DIFFUSE REFLECTIONS

When light is incident on a smooth surface it is reflected in the first medium. This reflection on a smooth surface is called **specular reflection.** When light is incident on a rough surface, it is reflected in many directions. This is called **diffuse reflection.** If the surface is so smooth that the distances between successive elevations on the surface are less than about one-eighth the wavelength of the light, there is very little diffuse reflection, and the surface is said to be *polished*. A surface therefore may be polished for radiation of long wavelengths but rough for light of short wavelengths. The wire-mesh "dish" shown in fig. 1.7 is very rough for light waves and is hardly mirror like. But, for long-wavelength radio waves, it is "polished" and is an excellent reflector.

Light reflecting from this page is diffuse. The page may be smooth to a radio wave, but, to a light wave, it is rough. Smoothness is relative to the wavelength of the illuminating waves. Rays of light striking this page encounter millions of tiny flat surfaces facing in all directions. The incident light, therefore, is reflected in all directions.

This is a desirable circumstance. It enables us to see objects from any direction or position. You can see the road ahead of your car at night, for instance because of diffuse reflection by the rough road surface. When the road is wet, however, it is smoother with less diffuse reflection, and therefore more difficult to see. Most of our environment is seen by diffuse reflection.

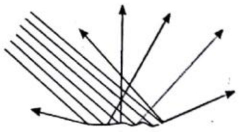


*Fig. 1.6 Diffuse reflection. Although reflection of each single ray obeys the law of reflection, the many different surface angles that light rays encounter in striking a rough surface produce reflection in many directions.*

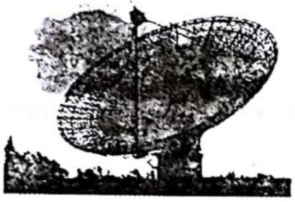


*Fig. 1.7 The open-mesh parabolic dish is a diffuse reflector for short-wavelength light but a polished reflector for long-wavelength radio waves.*

## ILLUSTRATION–1.1

**Two mirrors make an angle of 120° with each other as in Fig. 1.8 A ray is incident on mirror $M_1$ at an angle of 65° to the normal. Find the direction of the ray after it is reflected from mirror $M_2$.**

**SOLUTION:**

From the law of reflection, we know that the first reflected ray also makes an angle of 65° with the normal. Thus, this ray makes an angle of 90° – 65°, or 25°, with the horizontal. We build the geometric model triangle shown in Figure 1.8 from the triangle made by the first reflected ray and the two mirrors. The first reflected ray makes an angle of 35° with $M_2$ (because the sum of the interior angles of any triangle is 180°). This means that this ray makes an angle of 55° with the normal to $M_2$. Hence, from the law of reflection, the second reflected ray makes an angle of 55° with the normal to $M_2$.

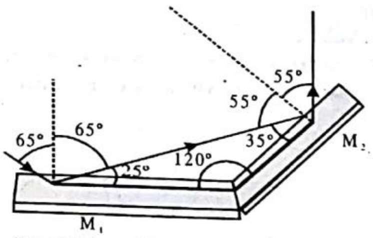



*Fig. 1.8 Mirrors $M_1$ and $M_2$ make an angle of 120° with each other.*

## CHECK Point

- **An observer on the west-facing beach of a large lake is watching the beginning of a sunset. The water is very smooth except for some areas with small ripples. The observer notices that some areas of the water appear blue and some appear pink. Why does the water appear to be different colors in different areas?**

**SOLUTION**

The different colors arise from specular and diffuse reflection. The smooth areas of the water specularly reflect the light from the west, which is the pink light from the sunset. The areas with small ripples reflect the light diffusely. Thus, light from all parts of the sky is reflected into the observers' eyes. Because most of the sky is still blue at the beginning of the sunset, these areas appear to be blue.

## REVERSIBILITY OF LIGHT RAYS:

*The fact that specular reflection displays equal angles of incidence and reflection means that there is a symmetry: if the ray had come in from the right instead of the left in the figure above, the angles would have looked exactly the same.* This is not just a pointless detail about specular reflection.

It's a manifestation of a very deep and important fact about nature, which is that the laws of physics do not distinguish between past and future. Cannonballs and planets have trajectories that are equally natural in reverse, and so do light rays. This type of symmetry is called time-reversal symmetry. Typically, time-reversal symmetry is a characteristic of any process that does not involve heat. For instance, the planets do not experience any friction as they travel through empty space, so there is no frictional heating.

We should thus expect the time-reversed versions of their orbits to obey the laws of physics, which they do. In contrast, a book sliding across a table does generate heat from friction as it slows down, and it is therefore not surprising that this type of motion does not appear to obey time-reversal symmetry. A book lying still on a flat table is never observed to spontaneously start sliding, sucking up heat energy and transforming it into kinetic energy.

Similarly, the only situation we've observed so far where light does not obey time-reversal symmetry is absorption, which involves heat. Your skin absorbs visible light from the sun and heats up, but we never observe people's skin to glow, converting heat energy into visible light. People's skin does glow in infrared light, but that doesn't mean the situation is symmetric. Even if you absorb infrared, you don't emit visible light, because your skin isn't hot enough to glow in the visible spectrum.

## REFLECTION AT A PLANE MIRROR

*Let's apply ray-diagram methods to the case of an object in front of a plane mirror in order to determine the position of the image of that object. Here's the configuration.*

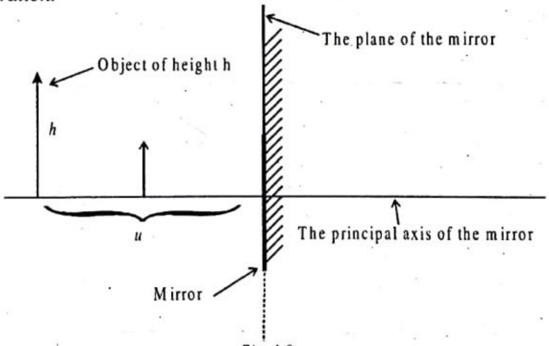



*Fig. 1.9*

We have an object of height h, a distance $u$ from the plane of the mirror. Our object is represented by an arrow. The tail of the arrow is on a reference line that is perpendicular to the plane of the mirror. I am calling the reference line "the principal axis of the mirror." The plane of the mirror is the infinite plane that contains the surface of the mirror.

We use the method of principal rays to determine the position of the image of the object. *In the method of principal rays, we consider only a few incident rays for which the reflected rays are particularly easy to determine.* Experimentally, we find that the position of the image is independent of the size of the mirror, so we consider the mirror to be as large as it needs to be for the principal rays to hit it. In particular, if a principal ray appears to miss the mirror in our diagram, we show the ray as reflecting off the plane of the mirror nevertheless. *Our Principal Ray I for the case at hand is one that approaches the plane of the mirror along a line that is parallel to the principal axis of the mirror.*

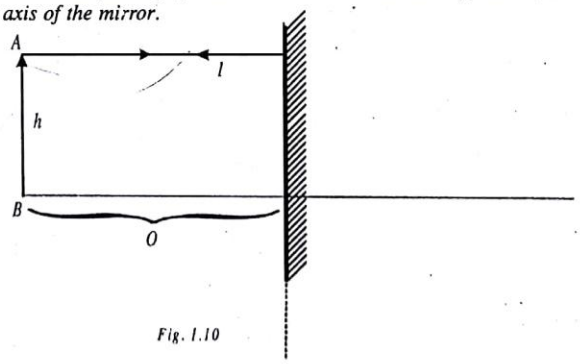



*Fig. 1.10*

According to the law of reflection, Principal ray *I* is reflected straight back on itself as depicted in the following diagram:

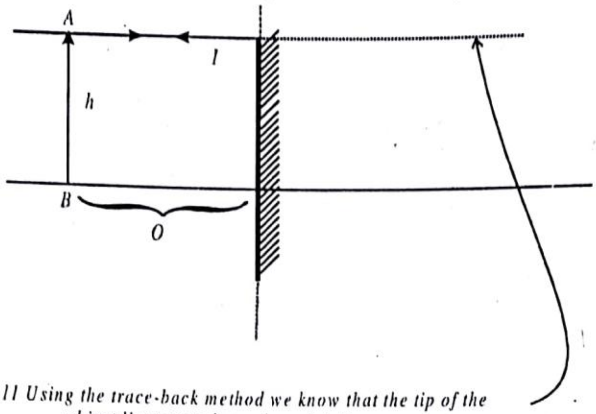



*Fig. 1.11 Using the trace-back method we know that the tip of the object lies somewhere along this line*

Principal ray II hits the mirror right where the principal axis of the mirror intersects the mirror. In accord with the Law of Reflection, with, for the ray in question, the principal axis of the mirror being the normal, the reflected ray makes the same angle with the principal axis of the mirror as the incident ray does.

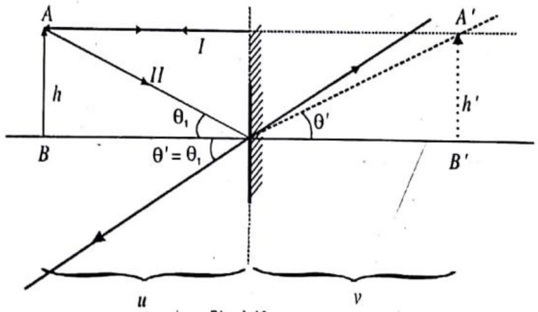



*Fig. 1.12*

Tracing back the second reflected ray, to the point where it intersects the first reflected ray traceback line, yields the position of the image of the tip of the arrow. The image height $h'$ is the distance between the same two parallel lines that the object height $h$ is the distance between. So, $h' = h$. Since vertical angles are equal, we have $\theta'$ in the diagram above being equal to $\theta_R$ which we know to be equal to $\theta_I$ from the law of reflection.

Thus the right triangle of side $h'$ and angle $\theta'$ is congruent to the triangle of height $h$ and angle $\theta_I$.

Hence, since corresponding sides of congruent triangles are equal, we have $v = u$. That is to say that the image distance, from the plane of the mirror, is equal to the object distance.

**Characteristics of image formed by plane mirror :**

1. Distance of object from mirror = Distance of image from mirror.
2. The image is laterally inverted (better word perversion).
3. The line joining the object point with its image is normal to the reflecting surface.
4. The size of the image is the same as that of the object.

*(i) For a real object the image is virtual and for a virtual object the image is real.*

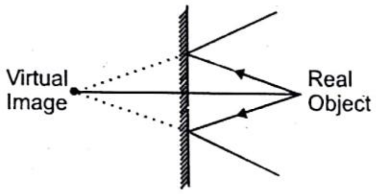



Fig. 1.13 (a)

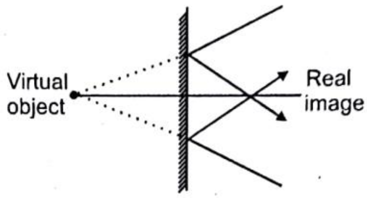



Fig. 1.13 (b)

*(ii) If keeping the incident ray fixed, the mirror is rotated by an angle θ, about an axis in the plane of mirror, the reflected ray is rotated through an angle 2θ.*

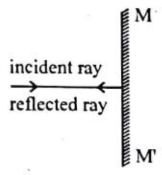



Fig. 1.14 (a)

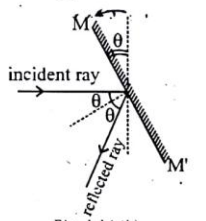



Fig. 1.14 (b)

# Knowledge ENHANCER

1. If two plane mirrors are kept inclined to each other at angle $\theta$ with their reflecting surfaces facing each other, multiple reflection takes place and more than one images are formed. Number of images ($n$) for $\theta \le 180°$ are given by :

$$n = \begin{cases} \dfrac{360°}{\theta} - 1 & \text{if } \dfrac{360°}{\theta} \text{ is even (object may be placed symmetrically or asymmetrically)} \\ \dfrac{360°}{\theta} - 1 & \text{if } \dfrac{360°}{\theta} \text{ is odd, the object is kept symmetrically (on bisector) w.r.t. the mirrors} \\ \dfrac{360°}{\theta} & \text{if } \dfrac{360°}{\theta} \text{ is odd, the object is kept asymmetrically (not on bisector) w.r.t. the mirrors} \\ \dfrac{360°}{\theta} & \text{if } \dfrac{360°}{\theta} \text{ is not an integer.} \end{cases}$$

All this is given below in a tabular form :

| S.No. | θ in degrees | m = (360/θ) | No. of images formed if object is placed | |
|---|---|---|---|---|
| | | | asymmetrically | symmetrically |
| 1 | 0 | ∞ | ∞ | ∞ |
| 2 | 30 | 12 | 11 | 11 |
| 3 | 45 | 8 | 7 | 7 |
| 4 | 60 | 6 | 5 | 5 |
| 5 | 72 | 5 | 5 | 4 |
| 6 | 75 | 4.8 | 4 | 4 |
| 7 | 90 | 4 | 3 | 3 |
| 8 | 112.5 | 3.2 | 3 | 3 |
| 9 | 120 | 3 | 3 | 2 |

(a) If an object is placed between two parallel mirrors ($\theta = 0°$), the number of images formed will be $(360/0) = \infty$ but of decreasing intensity in accordance with $I \propto (1/r^2)$.

(b) The number of images formed by two mutually perpendicular mirrors ($\theta = 90°$) will be 3. All these three images will lie on a circle with centre at $C$ – the point of interesection of mirrors $M_1$ and $M_2$ and whose radius is equal to the distance between $C$ and object $O$.

(c) Two mirrors inclined to each other at different angles may provide same number of images, e.g., for any value of $\theta$ between 90° and 120° the number of maximum images formed ($n$) is 3. This in turn implies that if $\theta$ is given, $n$ is unique but if n is given, $\theta$ is not unique.

(d) The number of images seen may be different from the number of images formed and depends on the position of observer relative to object and mirrors – e.g., if $\theta = 120°$ maximum number of images formed will be 3 (object not on bisector) but no. of images seen can only be 1, 2 or 3 depending on the position of observer.

2. If an object moves towards (or away from) a plane mirror at speed v, the image will also approach (or recede) at same speed $v$, i.e., the speed of image relative to object will be $v - (-v) = 2v$. Similarly if the mirror is moved towards (or away from) the object with a speed $v$ the image will move towards (or away from the object with a speed $2v$.

3. To locate the image of an object from an inclined mirror, see the perpendicular distance of the object from the mirror.

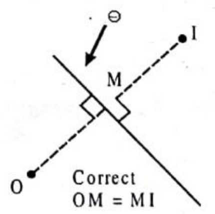



Fig. 1.15 (a)

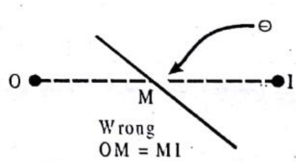



Fig. 1.15 (b)

4. If angle between two mirrors is $\theta$ after consecutive reflection total deviation $\delta = \delta_1 + \delta_2 = 2\pi - 2\theta$

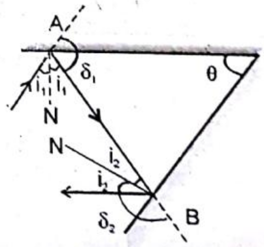



Fig. 1.16

## CHECK Point

- We see the bird and its reflection. Why do we not see the bird's feet in the reflection?

**SOLUTION**

The bird's feet are on the reflecting surface so the image of feet is formed at the same place where actually the feet are. So the image of the feet cannot be distinguished from the actual feet. This is so because the distance of the object from the reflecting surface is equal to that of the image from same surface.

Fig. 1.17

**ILLUSTRATION 1.2**

Find the minimum height of a mirror where one can see his full image.

**SOLUTION:**

Let ~~HL be the height~~ of the person and $E$, the position of his eyes. Now applying laws of reflection,

we have, $M'L' = \frac{1}{2}EL$ and $MH' = \frac{1}{2}HE$

Now, $H'L' = MM' - MH' - L'M'$

$= HL - \frac{1}{2}EL - \frac{1}{2}HE = HL - \frac{1}{2}HL = \frac{1}{2}HC$

So the required height of the mirror be half of the height of the person.

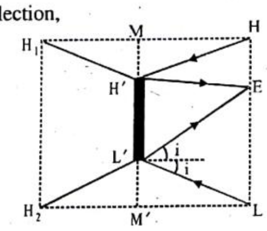


Fig. 1.18

**ILLUSTRATION 1.3**

Two plane mirrors are inclined at an angle θ. A ray of light is incident on one mirror at an angle of incidence i. The ray is reflected from this mirror, falls on the second mirror from where it is reflected parallel to the first mirror. What is the value of i, the angle of incidence in term of θ ?

**SOLUTION:**

The situation is illustrated in fig. 1.19. $XA$ is the incident ray. $BC$ is the final reflected ray. It is given that $BC$ is parallel to mirror $M_1$. Look at the assignment of the angles carefully. Now $N_2$ is normal to mirror $M_2$.

Therefore $\beta = \theta$

Then from $\Delta OAB$, $\theta + \beta + 90° - i = 180°$

or $\theta + \theta + 90° - i = 180°$ or $i = 2\theta - 90°$

Thus if the angle of incidence is $i = 2\theta - 90°$, then the final reflected ray will be parallel to the first mirror.

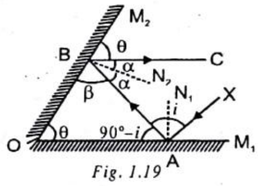


Fig. 1.19

**ILLUSTRATION 1.4**

Find the x and y co-ordinates, of the image of a point A (2, 0). MN is a plane mirror.

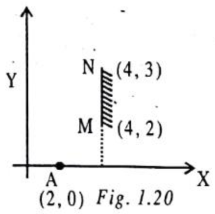


Fig. 1.20

**SOLUTION:**

Image of $A$ will be at $A'(6, 0)$. Perpendicular distance of image from plane mirror = perpendicular distance of object from plane mirror.

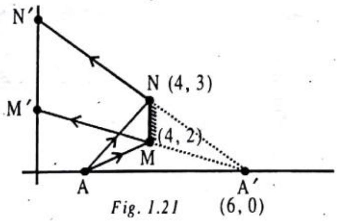


Fig. 1.21

## REFLECTION AT CURVED SURFACES

**Mirrors :** Mirrors can be found in every home, office, and public place. Without these simple instruments, doing many activities would be difficult or impossible. Mirrors can take on various forms depending on the purpose for which they are designed. For example, the rearview mirror of a vehicle does not provide much detail. Of more importance is that it indicates the position of other cars in as large an area as possible.

**Types of Mirrors :** In a bathroom mirror, we normally see ourselves in **actual size**, and the surface is flat. In a mirror that is sometimes used for shaving, the face appears very large. If we back up, though, after a moment of confusion, we appear small and in a reversed position. The surface is a **spherical** shape seen from the **inside (concave)**. In automobile rearview mirrors, the images often appear **small**, but you can see over a large area. Their surface is also curved, but the image is seen from the **outside (convex)**.

**Flat Mirrors :** When we place in **object** in front of a flat mirror, we see it as if it were located **behind** the mirror and in **specular symmetry**. This means that the image produced is the same as the object but with left and right reversed. As they are reflected, the light rays reach our eyes and we see the object in the prolongation of these rays.

**Concave Mirrors :** Imagine a **sphere** of **hollow** glass. If we cut out a spherical cap and plate it with silver on the outside, we have a **concave mirror** if we look at it from the hollow side. These mirrors, which are referred to as **convergent** mirrors, concentrate the light rays, causing them to arrive parallel to the main axis onto a point known as the **focal point**. Concave mirrors form **real images** that can be **projected** onto a screen if the object is farther away than the focal point. The image obtained is large if formed near the focal point or small if formed far away from the focal point. In both cases, the image is **reversed**. If we place the object closer than the focal point, the image is formed upright and large but virtual (i.e., it cannot be projected).

**Convex Mirrors :** If we plate the **inner surface** of a concave mirror with silver and look at it toward the **outward bulge**, we have a **convex** mirror. Mirrors of this type are also called **divergent** mirrors because the light beams that reach their surface and are **parallel** to their main axis are diverted in such a way that they **separate**, but their **extensions** come back together again in a point known as the **focal point**. The images produced by a convex mirror are always **virtual, upright**, and **small**.

## TERMS RELATED TO SPHERICAL MIRROR

**Centre of Curvature** ($C$) **:** It is the centre of sphere of which the mirror is a part.
**Radius of Curvature** ($R$) **:** It is the radius of the sphere of which the mirror is a part.
**Pole** ($P$)**:** It is the geometrical centre of the spherical reflecting surface.
**Principal Axis :** It is the straight line joining the centre of curvature to the pole.
**Focus** ($F$) **:** When a narrow beam of rays of light, parallel to the principal axis and close to it ( know as paraxial rays), is incident on the surface of a mirror, the reflected beam is found to converge ( concave mirror) or appear to diverge ( convex mirror) from a point principal axis. This point is called focus.
**Focal Length (f) :** It is the distance the pole and the principal focus. For spherical mirrors, $f = R/2$.

## RULES FOR RAY DIAGRAMS

(i) When a ray falls in the direction of centre of curvature of mirror then it reflects back along the same path.
(ii) A ray, parallel to the principal axis will after reflection, pass through the focus.
(iii) A ray, passing through the focus is reflected parallel to the principal axis.
Observe the following diagrams to draw ray diagrams.

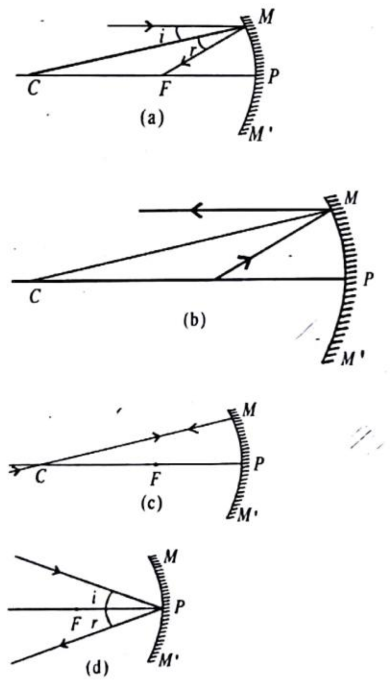


Fig. 1.22

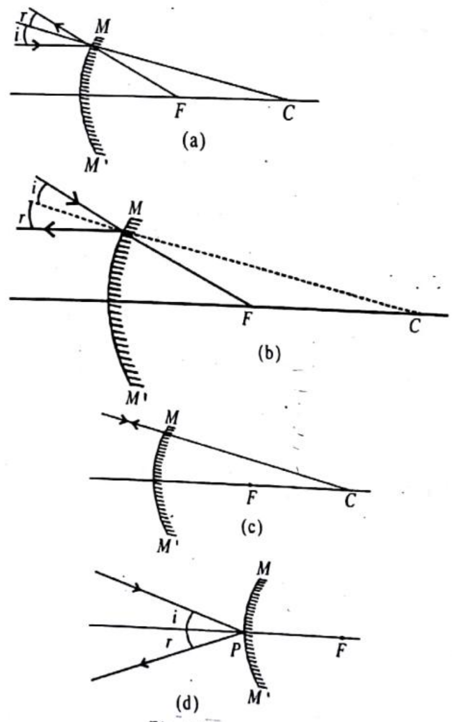


Fig. 1.23

## REFLECTION THROUGH CONCAVE MIRROR

$F \rightarrow$ Principal focus    $P \rightarrow$ Pole of mirror
$C \rightarrow$ Centre of curvature    $PC$ = Radius of curvature
PF = Focal length

When a narrow beam of light travelling parallel to the principal axis is incident on the reflecting surface of the concave mirror, the beam after reflection converge at a point on the principal axis.

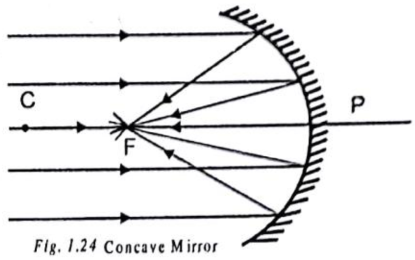
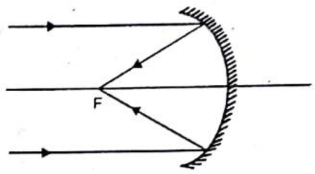
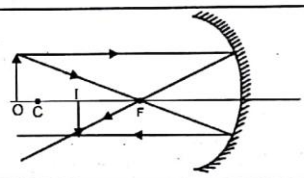
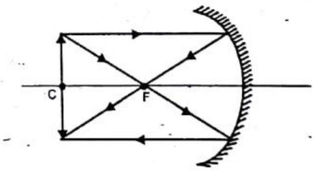
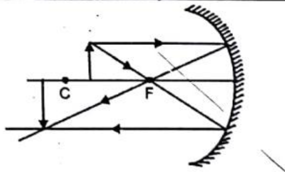
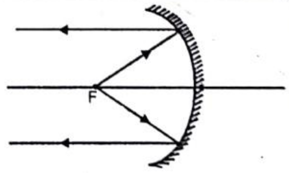
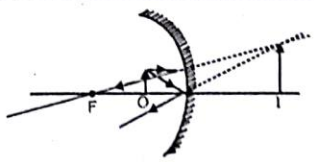



*Fig. 1.24* Concave Mirror

## IMAGE FORMED BY THE CONCAVE MIRROR

| Position of object | Position of image | Nature | Figure |
|---|---|---|---|
| At infinity | At the focus | Real, inverted & diminished |  |
| Between infinity & Centre of Curvature | Between focus & centre of curvature | Real, inverted & small in size |  |
| At centre of curvature | At centre of curvature | Real, inverted and of the same size |  |
| Between Focus & centre of curvature | Beyond centre of curvature | Real, inverted and enlarged |  |
| At Focus | At infinity | Real, inverted and very large |  |
| Between Focus & Pole | Behind the mirror | Erect, virtual & enlarged |  |

Makeup and shaving mirrors are concave mirrors. When you place your face between the mirror and its focal point, you see an enlarged virtual image of yourself. Concave mirrors are also used in a new method for displaying the speed of a car.

## REFLECTION THROUGH CONVEX MIRROR

When a narrow beam of light travelling parallel to the principal axis is incident on the reflecting surface of the mirror, the beam after reflection appear to diverge from a point on the principal axis.
When a ray incident on convex mirror in the direction of centre of curvature after reflection comes back along the same path.
When a ray incident on convex mirror parallel to the principal axis, after reflection, appears to come from the focus.
A ray appearing to pass through the focus is reflected parallel to the principal axis.

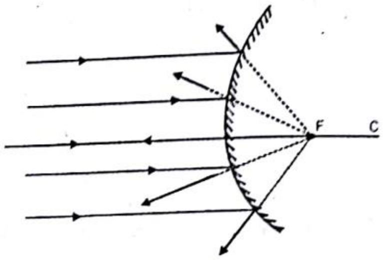


Fig. 1.25 Convex Mirror

## IMAGE FORMED BY CONVEX MIRROR

A convex mirror forms only virtual images for all positions of the real object. The image is always virtual, erect, smaller than the object and is located between the pole & the focus. The image becomes smaller and moves closer to the focus as the object is moved away from the mirror.

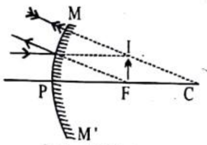


Fig. 1.26 (a)

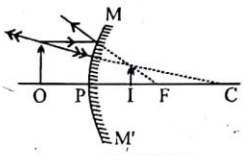


Fig. 1.26 (b)

The virtual image is diminished in size and upright, relative to the object. A convex mirror form a virtual image of the object, no matter where in front of the mirror the object is placed. Because of the shape of convex mirrors, they give a wider field of view than do other types of mirrors. Therefore, they are often used for security purposes, as in figure.

Fig. 1.27 : Security mirror

A mirror with a wide field of view is also needed to give a driver a good rear view. Thus, the outside mirror on the passenger side is often a convex mirror. Printed on such a mirror is usually the warning "vehicles in mirror are closer than they appear."

Fig. 1.28 : Rear view mirror

The reason for the warning is that the virtual image in figure is reduced in size and therefore looks smaller, just as a distant object would appear in a plane mirror. An unwary driver, thinking that the side-view mirror is a plane mirror, might incorrectly deduce from the small size of the image that the car behind is far enough away to ignore.

## COMPARING THE FIELDS OF VIEW OF A PLANE MIRROR AND A CONVEX MIRROR

For a fair comparison to be made the two mirrors must be the same size and the eye must be placed at the same distance from each of them. The maximum angle of view is obtained when the angle of reflection at the mirror is a maximum, i.e., when the normal to the mirror are drawn at the extreme edges of the mirror.

The normals to the convex mirror are lines which are continuations of the radii at the edges of the mirror. Once the angles of reflection have been drawn, equal angles must be drawn on the other side of the normals to give the position of the incident rays. The angle of incidence for the convex mirror is much greater than the angle of incidence for the plane mirror, hence the convex mirror has a greater field of view that the plane mirror.

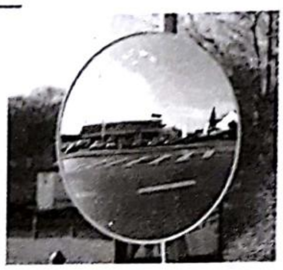


Fig. 1.29

## SIGN CONVENTION

(1) All distances are measured from the pole.

(2) The distance measured along the direction of propagation of light are taken as positive and the direction opposite to the propagation of light is taken as negative.

(3) The distances (heights) measured above the principal axis i.e. along positive $Y$ axis, are taken as positive while distances below the principal axis i.e. along negative $Y$ axis are taken as negative.

**Note that in this convention, the focal length ($f$) and radius of curvature ($R$) are negative for a concave mirror and positive for a convex mirror.**

The sign convention can be summarized in the following figure.

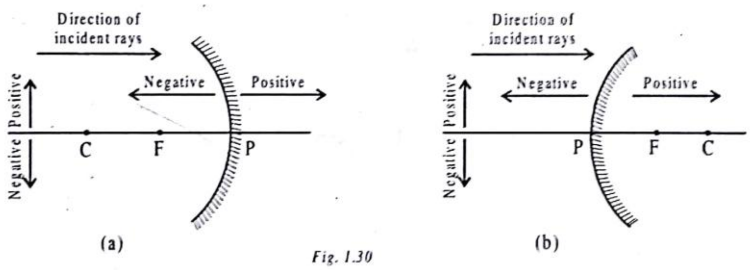



Fig. 1.30

**Note : Many Students get confused in applying sign convention and a small error in sign of one variable will throw all your calculation. Please study 3 points carefully ( put known quantities with proper sign unknown quantity will come automatically with proper sign).**

*In following situations, the sign convention has been applied.*

1. Consider the mirror shown in Fig. 1.31 (a). Here, the object is on the left and image is also on the left. The mirror is a concave mirror. The incident ray is directed from left to right and so the positive X-axis is also from left to right. Here, Object distance $u = -PO$, Image distance $v = -PI$, Radius of curvature $R = -PC$, Focal length $f = -ve$.

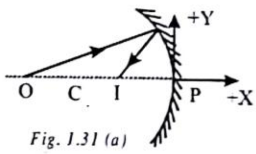



Fig. 1.31 (a)

2. Consider the mirror shown in Fig. 1.31 (b). Here, the object is on the left and image is on the right and the mirror concave. The incident ray is once again from left to right and so the positive X-axis.
Here, Object distance $u = -PO$, Image distance $v = +PI$, Radius of curvature $R = -PC$, Focal length $f = -ve$.

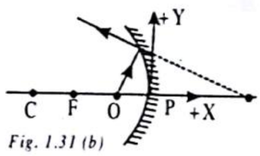



Fig. 1.31 (b)

3. Consider the mirror shown in Fig. 1.31 (c). Here, the object is virtual and on the left, image is also on the right and the mirror is a convex. The incident ray is from the right and the positive X-axis is from right to left. Here, Object distance $u = +PO$, Image distance $v = -PI$, Radius of curvature $R = +PC$,
Focal length $f = +ve$.

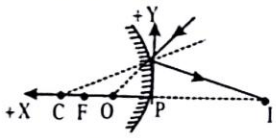



Fig. 1.31 (c)

## RELATION BETWEEN FOCAL LENGTH ($f$) AND RADIUS OF CURVATURE ($R$) FOR SPHERICAL MIRRORS

The focal length ($f$) of a mirror is half of the radius of curvature ($R$), that is, $f = \frac{R}{2}$

4. **Proof:** In Fig. 1.32, incident ray $OX$ is parallel to the principal axis. After reflection, it actually passes through focus $F$ in case of concave mirror and appears to come from focus $F$ in case of a convex mirror. $CXN$ is normal to mirror at $X$.

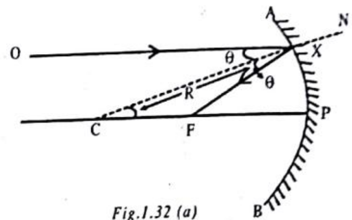


Fig.1.32 (a)

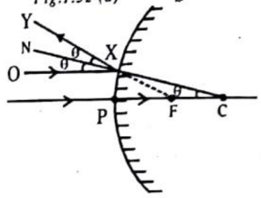


Fig. 1.32 (b)

For concave mirror (Fig.1.32 (a) (because $\angle i = \angle r$)

$\angle OXC = \angle FXC = \theta$

But $\angle OXC = \angle XCF$ (alternate angles)

For convex mirror (Fig. 1.32 (b)

$\angle OXN = \angle YXN = \theta$

But $\angle OXN = \angle XCF$ (corresponding angles)

and $\angle YXN = \angle FXC$ (vertically opposite)

Hence (in both cases), $\angle FXC = \angle XCF$ there fore, in $\Delta FCX$, $FC = FX$

For mirror of small aperture, $X$ will be near $P$, then $FX = FP$

Hence, $FC = PF$ and $2PF = PF + PF = PF + FC = PC$ i.e. $2f = R$ or $f = R/2$ (Proved).

## CHECK Point

- **Her eye at point P looks into the mirror. Which of the numbered cards can she see reflected in the mirror?**

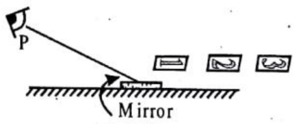


Fig. 1.33

### SOLUTION

Card number 2, she can see through the mirror. According to law of reflection, angle of incidence is equal to angle of reflection. Light ray coming from card number 2 makes the same angle with the normal at the point of incidence as the light ray going to eye makes with the normal.

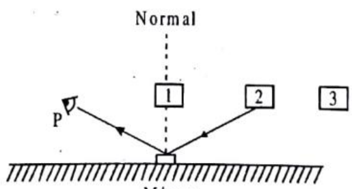



Fig. 1.34

**ILLUSTRATION 1.5**

The radius of curvature of a spherical mirror is 20 cm. What is its focal length ?

**SOLUTION:**

$$f = \frac{R}{2} = 10\text{cm.}$$

## MIRROR FORMULA

A relationship among the object distance ($u$), the image distance ($v$) and the focal length ($f$) of a mirror is called the mirror formula. The formula is given by

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

**Proof:** Take an object $AB$ beyond C of a concave mirror $MM'$. A ray $AD$ parallel to principal axis passes through focus after reflection. Another ray $AE$ which is passing through $C$ comes back along the same path after reflection. These two reflected rays intersect at $A'$. From $A'$ draw perpendicular $A'B'$ on the principal axis. So $A'B'$ is real and inverted image which is formed between $C$ and $F$ which is small than the object in size.

Draw $DG$ perpendicular to the principal axis. So, applying sign convention, we get $PB = -u$; $PB' = -v$; $PF = -f$; $PC = -2f$

In $\Delta ABC$ and $\Delta A'B'C$,

$\angle ABC = \angle A'B'C = 90°$

$\angle ACB = \angle A'CB'$ (Vertically opposite angles)

$\therefore \Delta ABC \sim \Delta A'B'C$ ($AA$ similarity)

$\frac{AB}{A'B'} = \frac{BC}{B'C}$ (Corresponding sides of similar triangles are in proportion) .........(1)

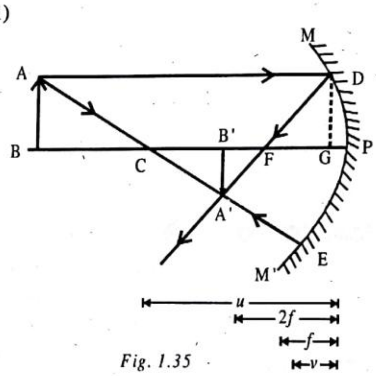



*Fig. 1.35*

In $\Delta DGF$ and $\Delta A'B'F$,

$\angle DGF = \angle A'B'F = 90°$

$\angle DFG = \angle A'FB'$ (Vertically opposite angles)

$\Delta DGF \sim \Delta A'B'F$ ($AA$ similarity)

$\frac{DG}{A'B'} = \frac{GF}{B'F}$ (Corresponding sides of similar triangles are in proportion)

But AB = DG (the perpendicular distance between two parallel lines are equal)

$\therefore \frac{AB}{A'B'} = \frac{GF}{B'F}$ ............(2)

From (1) and (2), we get, $\frac{BC}{B'C} = \frac{GF}{B'F}$ ..........(3)

Let us assume that mirror is very small,

$\therefore$ G and P are very close to each other so that GF = PF.

From (3), $\frac{BC}{B'C} = \frac{PF}{B'F} \Rightarrow \frac{PB-PC}{PC-PB'} = \frac{PF}{PB'-PF} \Rightarrow \frac{-u-(-2f)}{-2f-(-v)} = \frac{-f}{-v-(-f)}$

$\Rightarrow \frac{-u+2f}{-2f+v} = \frac{-f}{-v+f} \Rightarrow (-v+f)(-u+2f) = -f(-2f+v)$

$\Rightarrow\ vu - 2fv - fu + 2f^2 = 2f^2 - fv \Rightarrow uv = -fv + 2fv + fu$

$\therefore uv = vf + uf$

Dividing both sides by $uvf$,

$\frac{uv}{uvf} = \frac{vf}{uvf} + \frac{uf}{uvf} \Rightarrow \frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

## ILLUSTRATION 1.6

An object is placed at a distance of 10 cm from a convex mirror of focal length 15 cm. Find the position and nature of the image.

**SOLUTION:**

Given $u = -10$ cm, $f = +15$ cm, $v = ?$

Using the mirror formula $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$, we have

$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{15} - \frac{1}{(-10)}$ or $\frac{1}{v} = \frac{1}{15} + \frac{1}{10} = \frac{2+3}{30} = \frac{5}{30}$ or $v = \frac{30}{5} = 6$ cm.

Hence, the image is formed at a distance of 6 cm. behind the mirror. The image is virtual and erect.

**ILLUSTRATION–1.7**

We wish to obtain an erect image of an object, using a concave mirror of focal length 15 cm. What should be the range of distance of the object from the mirror ? What is the nature of the image? Is the image larger or smaller than the object? Draw a ray diagram to show the image formation in this case.

**SOLUTION :**

$f = -15$ cm.

For getting an erect image using a concave mirror the object should be placed at a distance less than the focal length (i.e.) 15 cm from pole. Image will be virtual, enlarged are erect.

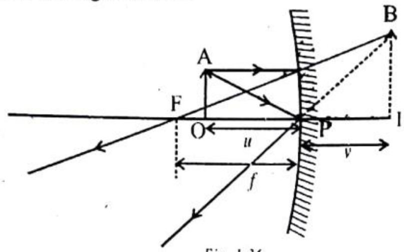



Fig. 1.36

**ILLUSTRATION–1.8**

A concave mirror and a convex mirror are placed co-axially, their reflecting surfaces facing each other. Their focal lengths are 15 and 12 cm respectively. An object placed between them is 20 cm from the concave mirror. The image formed by it is at the object itself. Calculate the distance of the concave mirror from the object.

**SOLUTION :**

In a concave mirror for the image to be formed at the object itself, the latter must be at the centre of curvature. But here, it is at a distance of 20 cm from mirror whose distance is not the radius of curvature. The radius of curvature is twice the focal length or 2 × 15 or 30 cm. The fact of the matter is the reflected rays from the concave mirror are reflected back along the same path forming the image at the object itself. This can happen only if the reflected rays falling on the mirror are normal to the mirror.

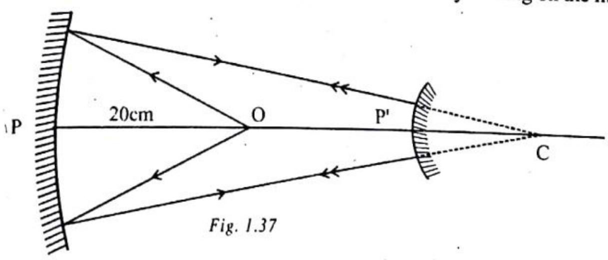



Fig. 1.37

$O$ is object. $OP = 20$ cm, $f = 15$ cm (of concave mirror)

The reflected rays from concave mirror are reflected back by convex mirror.

$\therefore$ $C$ must be centre of curvature of the latter. So its radius of curvature = twice its focal length i.e. $12 \times 2$ or 24 cm.

Now, if there were no convex mirror, the concave mirror would form an image of $O$ at $C$. Then we would have for concave mirror.

$u = +20$ cm, $f = +15$ cm, $v = PC = ?$

Now, $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$ i.e., $\frac{1}{v} + \frac{1}{+20} = \frac{1}{+15}$

$\therefore$ $\frac{1}{v} = \frac{1}{15} - \frac{1}{20} = \frac{1}{60}$ or $v = PC = 60$ cm

But we want $OP'$

Now $PO' = PC - P'C = 60 - 2 \times 12 = 36$ cm.

($\because$ $P'C$ = radius of curvature of convex mirror i.e. twice its focal length)

## MAGNIFICATION

If the mirror is plane, the size of the image is always equal to the size of the object. But the case is different for a curved mirror. The size of the image is different from the size of the object is such a 'mirror'. Image may be greater or smaller in size than the object depending upon the nature of the mirror or the location of the object.

Let $I$ and $O$ be the size of the image and the object respectively. The ratio $\frac{I}{O}$ is called **magnification**, and it is denoted by $m$. It turns out that

$$m = \frac{I}{O} = -\frac{v}{u}$$

Here $u$ and $v$ represent the distance of the object and the image from the pole of the mirror respectively.
$m$ can be positive or negative. If $m$ is positive, it means that $I$ and $O$ are both on the same side of the principal axis. That is, image is erect. Similarly, if m is negative, it means that $I$ and $O$ are on opposite sides of the principal axis. That is image is inverted.

## OTHER FORMULAE OF MAGNIFICATION

We have

$$m = -\frac{v}{u} \qquad \text{...........(1)}$$

By mirror formula,

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v} \qquad \text{...........(2)}$$

Dividing both sides, of (2 ) by $v$, we get

$$\frac{v}{f} = \frac{v}{u} + 1$$

$$\Rightarrow \frac{v}{u} = \frac{v}{f} - 1$$

$$\text{or} \quad \frac{v}{f} = \frac{v-f}{f} \qquad \text{...........(3)}$$

From (1) & (3),

$$m = -\left(\frac{v-f}{f}\right)$$

$$\Rightarrow \boxed{m = \frac{f-v}{f}} \qquad \text{...........(4)}$$

Dividing both sides of (2) by $u$, we get

$$\frac{u}{f} = 1 + \frac{u}{v}$$

$$\Rightarrow \frac{u}{v} = \frac{u}{f} - 1 = \frac{u-f}{f}$$

$$\therefore \frac{v}{u} = \frac{f}{u-f} \qquad \text{...........(5)}$$

From (1) and (5), $m = -\left(\frac{f}{u-f}\right)$ $\boxed{m = \frac{f}{f-u}}$ ...........(6)

**ILLUSTRATION – 1.9**

An object, 4.0 cm in size, is placed at 25.0 cm in front of a concave mirror of focal length 15.0 cm. At what distance from the mirror should a screen be placed in order to obtain a sharp image? Find the nature and the size of the image.

**SOLUTION:**

Object-size, $h = +4.0$ cm; Object-distance, $u = -25.0$ cm; Focal length, $f = -15.0$ cm;
Image-distance, $v = ?$ Image-size, $h' = ?$

From $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$ or $\frac{1}{v}=\frac{1}{f}-\frac{1}{u}=\frac{1}{-15.0}-\frac{1}{-25.0}=-\frac{1}{15.0}+\frac{1}{25.0}$

or $\frac{1}{v}=\frac{-5.0+3.0}{75.0}=\frac{-2.0}{75.0}$ or $v=-37.5$ cm.

The screen should be placed at 37.5 cm. from the mirror. The image is real.

Also, magnification, $m=\frac{h'}{h}=-\frac{v}{u}$ or $h'=-\frac{vh}{u}=\frac{(-37.5\text{cm})(+4.0\text{cm})}{(-25.0\text{cm})}$

Height of the image, $h' = -6.0$ cm.
The image is inverted and enlarged.

**ILLUSTRATION – 1.10**

A convex mirror used for rear-view on an automobile has a radius of curvature of 3.00 *m*. If a bus is located at 5.00 *m* from this mirror, find the position, nature and size of the image.

**SOLUTION:**

Radius of curvature, $R = +3.00\,m$; Object-distance, $u = -5.00\,m$; Image-distance, $v = ?$ Height of the image, $h' = ?$

Focal length, $f = R/2 = +\frac{3.00\text{m}}{2} = +1.50$ m

Since $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$ or $\frac{1}{v}=\frac{1}{f}-\frac{1}{u}=+\frac{1}{1.50}-\frac{1}{(-5.00)}=\frac{1}{1.50}+\frac{1}{5.00}=\frac{5.00+1.50}{7.50}$

$v=\frac{+7.50}{6.50}=+1.15m$

The image is 1.15*m* at the back of the mirror.

Magnification, $m=\frac{h'}{h}=-\frac{v}{u}=-\frac{1.15m}{-5.00m}=+0.23$

The image is virtual, erect and smaller in size by a factor of 0.23.

**ILLUSTRATION – 1.11**

An object of size 7.0 cm is placed at 27 cm in front of a concave mirror of focal length 18 cm. At what distance from the mirror should a screen be placed, so that a sharp focussed image can be obtained? Find the size and the nature of the image.

**SOLUTION:**

$h_0 = 7.0$ cm, $u = -27$ cm, $f = -18$ cm.

Using, $\frac{1}{f}=\frac{1}{v}+\frac{1}{u}$, we get $\frac{1}{v}=\frac{1}{f}-\frac{1}{u}=\frac{1}{-18}-\frac{1}{(-27)}=\frac{-1}{18}+\frac{1}{27}=\frac{-3+2}{54}=\frac{-1}{54}$ or $v=-54$ cm.

Using $m=\frac{h_i}{h_0}=\frac{v}{u}$ we get, $h_I=h_0\frac{v}{u}=7\times\frac{-54}{-27}=14$cm.

Since $h_i > h_0$, the image is enlarged.
Since $v$ is $-ve$, the image is real and inverted.

**ILLUSTRATION–1.12**

A concave makeup mirror is designed so the virtual image is twice the size of the object, when the distance between the object and mirror is 15 cm (a) Determine the radius of curvature of the mirror. (b) Draw a ray diagram to scale, showing this situation.

**SOLUTION:**

The magnification is, $m = -\frac{v}{u} = +2$ where $u$ is 15 cm. Therefore, $v = -2u = -3.0 \times 10^1$ cm.

Therefore, the focal length is found from $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ which yields $f = +30$ cm. Therefore, $R = 2f = 60$ cm.

**ILLUSTRATION–13**

The image of an object viewed in a concave mirror of focal length 25.0 cm appears 75.0 cm in front of the mirror. Find the location of the object and the magnification.

**SOLUTION:**

We have, $\frac{1}{u} = \frac{1}{f} - \frac{1}{v} = \frac{1}{25.0} - \frac{1}{75.0} = 0.0267\ \text{cm}^{-1} \Rightarrow u = 37.5$ cm.

The magnification is, $m = -\frac{v}{u} = \frac{-(75.0\ \text{cm})}{37.5\ \text{cm}} = -2.00$

**ILLUSTRATION–1.14**

A concave mirror of focal length $f$ produces a real image n times the size of the object. What is the distance of the object from the mirror.

**SOLUTION:**

$$m = -n\ ;\ m = \frac{f}{f-u}$$

$$-n = \frac{-f}{-f-u} \Rightarrow nf + nu = -f$$

$$nu = -f - nf \Rightarrow u = \frac{-(n+1)}{n} f$$

**ILLUSTRATION–1.15**

The focal length of a concave mirror is 30 cm. Find the position of the object in front of the mirror, so that the image is three times the size of the object.

**SOLUTION:**

Here image can be real or virtual. If the image is real

$f = -30$ cm, $u = ?$, $m = -3$

$$m = \frac{f}{f-u} \Rightarrow \quad 3 - \frac{-30}{-30-u} \Rightarrow \quad u = -40\ \text{cm}.$$

If the image is virtual

$$m = \frac{f}{f-u} \Rightarrow \quad 3 = \frac{-30}{-30-u} \Rightarrow \quad u = -20\ \text{cm}.$$

**ILLUSTRATION - 1.16**

The sun (diameter D) subtends an angle θ radian at the pole of a concave mirror of focal length f. What is the diameter of the image of the sun formed by the mirror?

**SOLUTION:**

Since the sun is very distant, $u$ is very large and so $1/u$ is practically zero

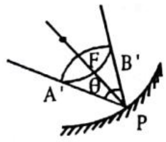



Fig. 1.38

$$\frac{1}{u} \approx 0 \qquad \frac{1}{v}+\frac{1}{u}=\frac{1}{f}$$

$$\frac{1}{v}=-\frac{1}{f} \qquad v=-f$$

The image of sun will be formed at the focus and will be real, inverted and diminished

$A'B\,\theta$ = height of image

$$\theta=\frac{\text{Arc}}{\text{Radius}}=\frac{A'B'}{FP} \Rightarrow \theta=\frac{d}{f} \Rightarrow d=f\theta$$

## POWER OF A MIRROR

The power of a mirror is defined as its capacity to converge or diverge. Mathematically, it is defined as inverse of focal length. For concave mirror power is positive as it is a converging mirror and for convex it is negative as it is a diverging mirror.

$$P=\frac{1}{f(\text{in } m)} \qquad =\frac{100}{f(\text{in cm})}$$

The unit of power is diopter.

In sign convention, $f$ (or $R$) is negative for concave or converging mirror and positive for convex or diverging mirror.

## NEWTON'S FORMULA

This formula provides a relationship among the focal length ($f$), the distance of the object from focus ($x$) and the distance of the object from focus ($y$).

This can be expressed as

$$xy=f^2$$

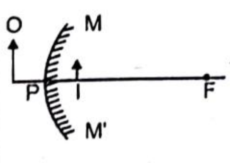
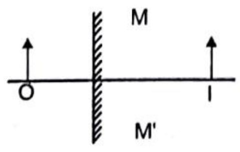
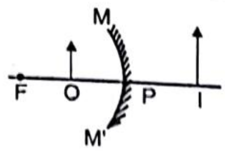
Note that here the object distance and the image distance are measured from the focus of the mirror not from the pole.

## IDENTIFICATION OF MIRROR BY THE SIZE AND NATURE OF THE IMAGE

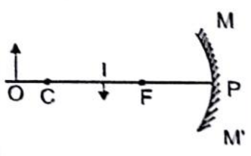
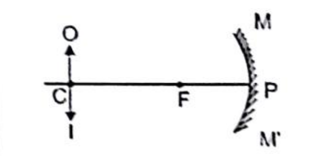
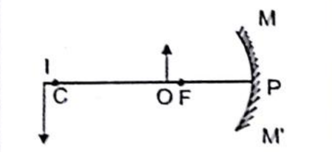
(i) If object and image are of same nature (i.e. both on the same side of the mirror) then they will be inverted.

(ii) If the object and image are on the opposite sides of the mirror then image is erect relative to object.

For real extended object if the image formed by a single mirror is erect it is always virtual (i.e. $m$ is +ve) and in this situation if the size of image is

| Smaller than object, the mirror is convex | Equal to object, the mirror is plane | Larger than object, the mirror is concave |
|---|---|---|
|   m < +1 |   m = +1 |   m > +1 |

So, by observing the size of erect image in a mirror we can decide the nature of the mirror i.e. whether it is convex, concave or plane. For real extended object if the image formed by a single mirror is inverted it is always real (i.e., $m$ is $-ve$) and the mirror is concave. In this situation if the size of image is

| Smaller than object, object is between the ∞ and C and image is between F and C | Equal to object, object is at C and image is at C | Larger than object, object is between C and F and image is between C & ∞ |
|---|---|---|
|   $m < -1$ |   $m = -1$ |   $m > -1$ |

*As every part of a mirror forms complete image, if a part of mirror (say half) is obstructed (say covered with black paper) full image will be formed but intensity will be reduced.*

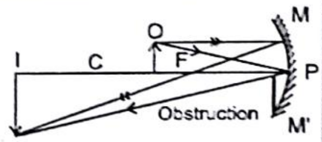


Fig. 1.39

## REFRACTION AT PLANE SURFACES

The bending of the light ray from its path in passing from one medium to the other medium is called refraction of light.

If the refracted ray bends towards the normal relative to the incident ray, then the second medium is said to be denser than the first medium. But if the refracted ray bends away from the normal, then the second medium is said to be rarer than the first medium.

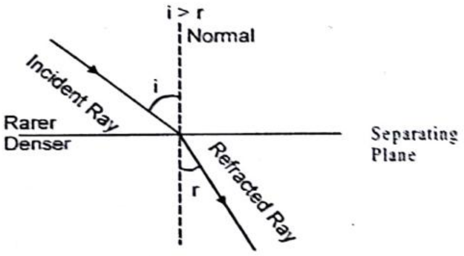


Fig. 1.40 (a)

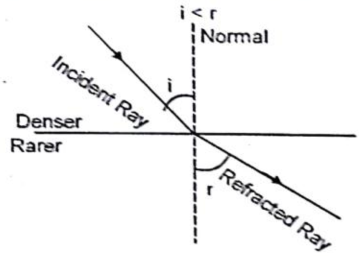


Fig. 1.40 (b)

To gain a better understanding of the bending of light in refraction, look at the pair of toy cart wheels in Fig. 1.40 (c). The wheells roll from a smooth sidewalk onto a grass lawn. If the wheels meet the grass at an angle, as the Fig. 1.40 (c), shows they are deflected from their straightline course. Note that the left wheel slows first when it interacts with the grass on the lawn. The right wheel maintains its higher speed while on the sidewalk. It pivots about the slower-moving left wheel because it travels farther in the same time. So the direction of the rolling wheels is bent toward the "normal," the black dashed line perpendicular to the grass-sidewalk border in figure.

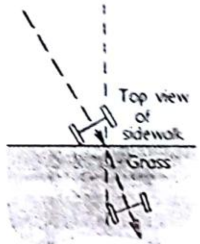


Fig. 1.40 (c) The direction of the rolling wheels changes when one wheel slows down before the other does.

Fig. 1.41 (a) shows how a light wave bends in a similar way. Note the direction of light, indicated by the arrow (the light ray). Also note the *wave fronts* drawn at right angles to the ray. (If the light source were close, the wave fronts would appear circular; but, if the distant sun is the source, the wave fronts are practically straight lines.) The wave fronts are everywhere at right angles to the light rays. In the Fig. 1.41 (b), the wave meets the water surface at an angle. This means that the left portion of the wave slows down in the water while the remainder in the air travels at the full speed of light, *c*. The light ray remains perpendicular to the wave front and therefore bends at the surface. It bends like the wheels bend when they roll from the side-walk onto the grass. In both cases, the bending is caused by a change of speed.

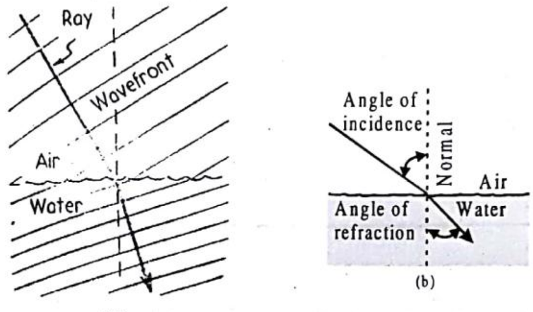



*Fig.1.41. The direction of the light waves changes when one part of the wave slows down before the other part.*

Fig. 1.42, shows a beam of light entering water at the left and exiting at the right. The path would be the same if the light entered from the right and exited at the left. The light paths are reversible for both reflection and refraction. If you see someone's eyes by way of a reflective or refractive device, such as a mirror or a prism, then that person can see you by way of the device also.

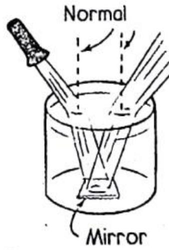



*Fig.1.42. When light slows down in going from one medium to another, as it does in going from air to water, it bends toward the normal. When it speeds up in traveling from one medium to another, as it does in going from water to air, it bends away from the normal.*

Refraction causes many illusions. One of them is the apparent bending of a stick that is partially submerged in water. The submerged part appears closer to the surface than it actually is. The same is true when you look at a fish in water. The fish appears nearer to the surface and closer than it really is (Fig. 1.43). If we look straight down into water, an object submerged 4 meters beneath the surface appears to be only 3 meters deep. Because of refraction, submerged objects appear to be magnified.

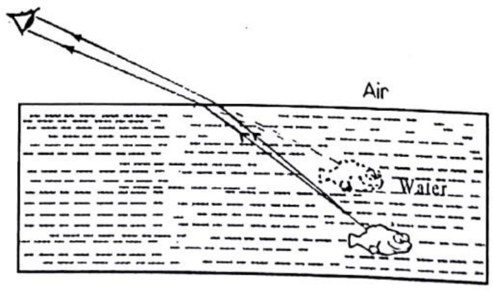



*Fig.1.43 Because of refraction, a submerged object appears to be nearer to the surface than it actually is*

Refraction occurs in the earth's atmosphere. Whenever we watch a sunset, we see the sun for several minutes after it has sunk below the horizon (Fig. 1.44). The earth's atmosphere is thin at the top and dense at the bottom. Because light travels faster in thin air than in dense air, parts of the wave fronts of sunlight at high altitude travel faster than parts closer to the ground. Light rays bend. The density of the atmosphere changes gradually, so light rays bend gradually and follow a curved path. So we gain additional minutes of daylight each day. Furthermore, when the sun (or moon) is near the horizon, the rays from the lower edge are bent more than the rays from the upper edge. This shortens the vertical diameter, causing the sun to appear elliptical figure).

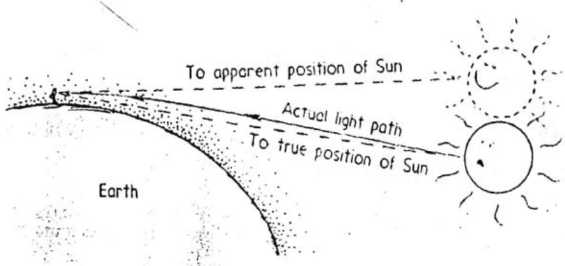



*Fig. 1.44. Because of atmospheric refraction, when the sun is near the horizon it appears to be higher in the sky.*

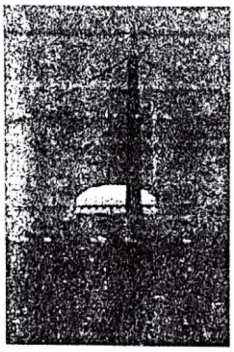


*Fig. 1.45. The sun is distorted by differential refraction.*

## REFRACTIVE INDEX

Light travels through a vacuum at a speed $c = 3.00 \times 10^8$ m/s. It can also travel through many materials, such as air, water and glass. Atoms in the material absorb, reemit and scatter the light, however. Therefore, light travels through the material at a speed that is less than $c$, the actual speed depending on the nature of the material.

To describe the extent to which the speed of light in a material medium differs from that in a vacuum, we use a parameter called the index of refraction (or refractive index).

## ABSOLUTE REFRACTIVE INDEX

It is defined as the ratio of speed of light in free space c to that in a given medium $v$,

i.e. $\mu$ or $n = \frac{c}{v}$ ...........(1)

It is a scalar and has no units and dimensions.

As in vacuum or free space, speed of light of all wavelengths is maximum and equal to $c$, so, for all wavelengths the refractive index of free space is minimum and is $\mu = \frac{c}{v} = \frac{c}{c} = 1$

For a given light, denser is the medium, lesser will be the speed of light and so greater will be the refractive index, e.g. as $v_{glass} < v_{water}$, $\mu_G > \mu_w$

i.e. for a given light refractive index depends on nature of medium [i.e., $\mu \propto (1/v)$]s

For a given medium (other than free-space), the speed of light of different wavelengths is different, i.e., $v \propto \lambda$ and $\mu = (c/v)$, $\mu \propto (\lambda)$ i.e. greater the wavelength of light lesser will be the refractive index e.g. $\lambda_r > \lambda_g$, so in water or glass $\mu_r < \mu_g$, i.e., for a given medium (other than free space) refractive index depends on wavelength of light.

As for light in free space $c = f\lambda_0$ and in a medium $v = f\lambda$

$$\mu = \frac{c}{v} = \frac{\lambda_0}{\lambda} \qquad \text{.........(2)}$$

i.e., for a given light and medium refractive index is equal to the ratio of wavelength of light in free space to that in the medium. Refractive index decreases with the increase in temperature.

## RELATIVE REFRACTIVE INDEX

When light passes from one medium to the other, the refractive index of medium 2 relative to 1 is written as ${}_1\mu_2$ and is defined as

$${}_1\mu_2 = \frac{\mu_2}{\mu_1} = \frac{(c/v_2)}{(c/v_1)} = \frac{v_1}{v_2} \qquad \text{.........(3)}$$

while using the concept of relative $\mu$, is must be kept in mind that :

$${}_2\mu_1 = \frac{\mu_1}{\mu_2} = \frac{v_2}{v_1} \qquad \text{So that, } ({}_1\mu_2)({}_2\mu_1) = \frac{v_1}{v_2} \times \frac{v_2}{v_1} = 1 \qquad \text{i.e., } {}_1\mu_2 = \frac{1}{{}_2\mu_1} \qquad \text{.........(5)}$$

Usually '$\mu$' is used for relative refractive index and it implies the refractive index of denser medium relative to rarer one, i.e.,

$$\mu = \frac{\mu_D}{\mu_R} = \frac{v_R}{v_D} > 1$$

In lens theory $\mu$ is used for the refractive index of material of lens relative to the medium, i.e.,

$\mu = \dfrac{(\mu)_{Lens}}{(\mu)_{Medium}}$ and can be greater than, less than or equal to unity.

## CHECK Point

- **If, while standing on the bank of a stream, you wished to spear a fish swimming in the water out in front of you, would you aim above, below, or directly at the observed fish to make a direct hit? If you decided instead to zap the fish with a laser, would you aim above, below, or directly at the observed fish? Defend your answer.**

**SOLUTION**

When you try to hit the fish with a spear, you need to aim below as the fish is actually at a lower depth than that observed by you from outside the water due to refraction of light.

When you aim with a laser light then also you should aim much below as the path of laser will change as it enters in water. Since it is going from rarer to denser medium, it bends towards the normal and deviates from the original path.

*If ${}_1\mu_2$, ${}_2\mu_3$ and ${}_3\mu_1$ be refractive index of medium 2 w.r.t. medium 1, refractive index of medium 3 w.r.t medium 2 and refractive index of 1 w.r.t. 3 respectively then ${}_1\mu_2 \times {}_2\mu_3 \times {}_3\mu_1 = 1$.*

## ILLUSTRATION 1.17

Light waves of 5895 Å wavelength travels from vacuum to a medium of refractive index of 1.5. Find the velocity of light and wavelength in medium.

**SOLUTION :**

If velocity of light in vacuum is $c$ then velocity of light in medium is $v = \dfrac{c}{n} = \dfrac{3\times10^8}{15} = 2\times10^8$ m/sec

wavelength of light in medium is $\lambda_w = \dfrac{\lambda}{n} = \dfrac{5895}{1.5} = 3930\ A^0$.

**ILLUSTRATION 1.18**

The refractive index of water is 4/3 and of glass is 3/2. Calculate the refractive index of glass with respect to water.

**SOLUTION :**

Let the 3 media be 1, 2 and 3, 1 for air, 2 for water, 3 for glass in that order.

Given : ${}_1\mu_2 = \frac{4}{3}$, ${}_2\mu_3 = ?$, ${}_3\mu_1 = \frac{1}{3/2}$   [$\because {}_1\mu_3 = \frac{3}{2}$ and $\therefore$ ${}_3\mu_1$ is the reciprocal of ${}_1\mu_3$]

Now using the formula, ${}_1\mu_2 \cdot {}_2\mu_3 \cdot {}_3\mu_1 = 1$ and substituting values, we have

$$\frac{4}{3} \cdot {}_2\mu_3 \cdot \frac{2}{3} = 1$$

$${}_2\mu_3 = \frac{1\times3\times3}{4\times2} = \frac{9}{8}$$

$\therefore$ The refractive index of glass with respect to water is 9/8

## Knowledge ENHANCER

**CAUCHY'S RELATION**

It gives relation between refractive index ($\mu$) and wavelength ($\lambda$) of light. The Cauchy's relation is given by

$$\mu = A + \frac{B}{\lambda^2}$$

where A and B are constants.

Thus,

$$\lambda_{red} > \lambda_{violet}$$

$$\Rightarrow \mu_{red} < \mu_{violet}$$

### LAWS OF REFRACTION

1. The incident ray, the refracted ray and the normal to the refracting surface at the point of incidence are in the same plane.
2. The angle of incidence and the angle of refraction satisfy the equation (you can refer to Fig. 1.46)

$$\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1}$$

*If the speed of light were the same in all media, refraction would not occur when light passes from one medium to another.*

## CHECK Point

- **If you place a glass test tube in water, you will be able to see the tube. If you place it in clear soybean oil, you may not be able to see it. What does this tell you about the speed of light in the oil and in the glass?**

**SOLUTION**

If a glass test tube is placed in water and it can be seen, this indicates the speed of light in glass and water is different. So refraction takes place.

When the same glass tube is placed in soyabean oil, it cannot be seen that means the speed of light is same in both oil and glass. So no refraction takes place between the two media.

**ILLUSTRATION 1.19**

The refractive index of a material is 1.33. If velocity of light in vacuum is $3 \times 10^8$ ms$^{-1}$, find the velocity of light in the material.

**SOLUTION:**

$$\mu = \frac{\text{Velocity of light in vacuum}}{\text{Velocity of light in material}}$$

$$\therefore \quad 1.33 = \frac{3\times10^8 \text{ ms}^{-1}}{\text{Velocity of light in material}}$$

$$\therefore \quad \text{Velocity of light in material} = \frac{3\times10^8}{1.33} = 2.25\times10^8 \text{ ms}^{-1}$$

**ILLUSTRATION 1.20**

The angle of incidence in air for a ray of light is 40°. If ray travels through water of refractive index 4/3, find angle of refraction.

**SOLUTION:**

$$^a\mu_w = \frac{\sin i}{\sin r}$$

$$\therefore \quad \sin r = \frac{\sin i}{^a\mu_w} = \frac{\sin 40}{4/3} = \frac{3\times0.6427}{4}$$

$$\sin r = 0.4820$$

$$\therefore \quad r = \sin^{-1}(0.4820) = 28.82° \text{ (approx.)}$$

## SNELL'S LAW

For any two media and for light of a given wavelength, the ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant.

$$\frac{\sin i}{\sin r} = \text{constant}, \text{ where } i = \text{incidence angle}, r = \text{refraction angle.}$$

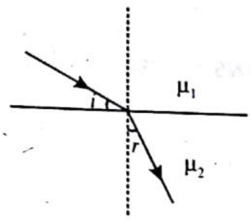


*Fig. 1.46*

## APPLICATION OF SNELL'S LAW

When light passes from rarer to denser medium it bends toward the normal. Using Snell's Law

$$\mu_1 \sin\theta_1 = \mu_2 \sin\theta_2$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{\mu_2}{\mu_1}$$

Thus, if $\mu_2 > \mu_1$ then $\theta_2 < \theta_1$

When light passes from denser to rarer medium it bends away from the normal.

From Snell's law, $\dfrac{\sin\theta_1}{\sin\theta_2} = \dfrac{\mu_2}{\mu_1}$

Thus, if $\mu_2 < \mu_1$ then $\theta_2 > \theta_1$

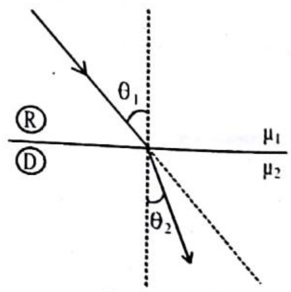


*fig. 1.47 (a)*

When light propagates through a series of layers of different medium, then according to Snell's law

$$\mu_1 \sin\phi_1 = \mu_2 \sin\phi_2 = \mu_3 \sin\phi_3 = \dots\dots\dots = \text{constant}$$

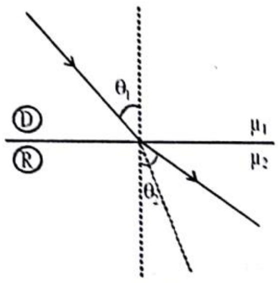



Fig. 1.47 (b)

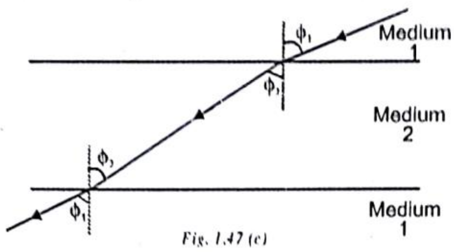



Fig. 1.47 (c)

**ILLUSTRATION—1.21**

Light reflected from a fish strikes the surface of the water at an angle of 38° to the normal. What is the angle of refraction of the light into the air ?

**SOLUTION:**

Snell's law gives, $n_w \sin\theta_1 = n_a \sin\theta_2$

$$\sin\theta_2 = (1.33)\sin 38°$$

$$\theta_2 = 55°.$$

**ILLUSTRATION—1.22**

A laser beam is directed at an angle θ, to the normal of one side of a rectangular block to fused quartz. Part of the light striking the side of the block passes into the block and strikes an adjacent face. For what angle θ will the laser beam be totally reflected in the block ?

**SOLUTION:**

Snell's law gives for the refraction into the block

$$(1.00)\sin\theta = n_2 \sin\theta_2$$

If the beam is totally internally reflected at the adjacent face, the incident angle on that face must be at least

$$\theta_c = \sin^{-1}(1.000/1.458) = 43.30°$$

Since the block is rectangular, $\theta_2 + \theta_c = 90°$ so $\theta_2$ is less than 46.70° for the internal reflection to occur.

$$\sin\theta = (1.458)\sin 46.70° = 1.06$$

The sine function cannot be greater than one, so the angle, θ, which will produce the internal reflection must be less than or equal to 90°. That is, all incident angles will cause the light to be totally internally reflected at the adjacent face as long as the light strikes that face.

**ILLUSTRATION—1.23**

Light strikes an interface between two materials of refractive indices $n_1$ and $n_2$, at an angle $\theta_1$ to the normal to the surface. Show that a ray of the light is bent towards the normal if $n_1 < n_2$ and that a ray is bent away from the normal if $n_1 > n_2$.

**SOLUTION:**

Snell's law gives for any light ray

$$\sin\theta_2 = \frac{n_1}{n_2}\sin\theta_1$$

If $n_1 < n_2$ then $\sin\theta_2 < \sin\theta_1$ and $\theta_2 < \theta_1$. This means that the ray is bent toward the normal.
If $n_1 > n_2$ then $\sin\theta_2 > \sin\theta_1$ and $\theta_2 > \theta_1$. This means that the ray is bent away from the normal.

**ILLUSTRATION–1.24**

One light wave is incident upon a plate of refractive index $\mu$. Find theincident angle $i$, for which refractive & reflective waves are mutually perpendicular.

**SOLUTION :**

$$\frac{\sin i}{\sin r} = \mu$$

Angle between refractive & reflective waves = $180° - (i + r) = 90° \Rightarrow i + r = 90°$

$$r = 90° - i \qquad \therefore \mu = \frac{\sin i}{\sin(90 - i)} = \frac{\sin i}{\cos i} = \tan i \Rightarrow i = \tan^{-1}(\mu)$$

## Knowledge ENHANCER

**Conditions of no refraction :** If light is incident normally on a boundary i.e., $\angle i = 0°$

Then from Snell's law

$\mu_1 \sin 0 = \mu_2 \sin r \Rightarrow \sin r = 0$ i.e. $\angle r = 0$

i.e., light passes undeviated from the boundary. (so boundary will be invisible)

If the refractive indices of two media are equal i.e., if,

$\mu_1 = \mu_2 = \mu$

Then from Snell's law

$\mu_1 \sin i = \mu \sin r$

$\Rightarrow \angle i = \angle r$ i.e.,

ray passes undeviated from the boundary with $\angle i = \angle r \neq 0$ and boundary will not be visible.

This is also why a transparent solid is invisible in a liquid if $\mu_s = \mu_L$

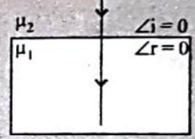



Fig. 1.48 (a)

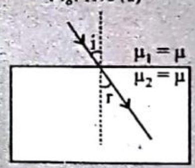



Fig. 1.48 (b)

## REFRACTION THROUGH A GLASS SLAB

Let us consider a glass slab of thickness $t$ and refractive index on which a ray $AB$ is incident at $B$. $BC$ and $CD$ are the refracted ray and emergent ray respectively. $x$ is the displacement in the emergent ray due to refraction.

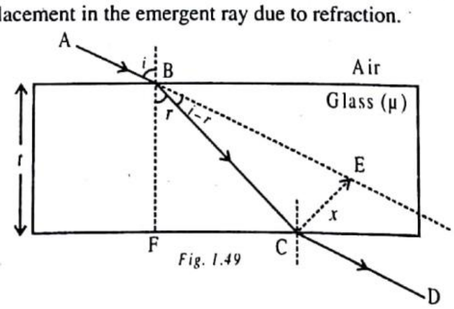



Fig. 1.49

From $\Delta BCE$,

$$\sin(i - r) = \frac{CE}{BC}$$

or $$\sin(i - r) = \frac{x}{BC} \qquad .....(1)$$

Also, from $\Delta BFC$,

$$\cos r = \frac{BF}{BC} = \frac{t}{BC} \qquad .....(2)$$

Equating $BC$ from (1) and (2), we get

$$\frac{x}{\sin(i-r)} = \frac{t}{\cos r}$$

$$\Rightarrow \quad x = \frac{t\sin(i-r)}{\cos r}$$

$$x = t\sec r.\sin(i-r)$$

$x$ is called the lateral displacement.

***Lateral displacement depends on the following factors.***

***(i) Refractive index of the medium ($\mu$)***

$$x \propto \mu$$

***(ii) Thickness of the medium ($t$)***

$$x \propto t$$

***(iii) Angle of incidence ($i$)***

$$x \propto i$$

***(iv) Wavelength of light ($\lambda$)***

$$x \propto \frac{1}{\lambda}$$

**ILLUSTRATION 1.25**

Figure 1.50, shows the path of ray of light passing through a glass slab. By geometrical construction calculate the refractive index of glass applying Snell's law.

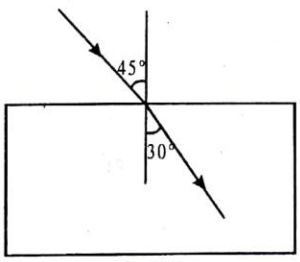



*Fig. 1.50*

**SOLUTION :**

AO is the incident ray on the surface of glass and OB is the refracted ray through the glass. With O as centre draw a circle of some suitable radius cutting the incident ray at A and the radius ray at B. Draw perpendiculars AC and BD to the normal COD.

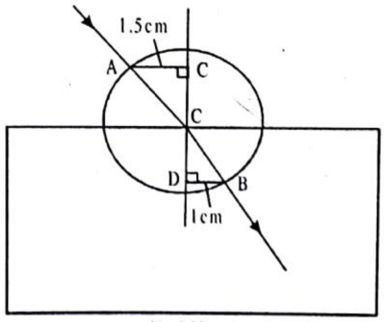



*Fig. 1.51*

Refractive index $\mu = \frac{\sin i}{\sin r} = \frac{AC}{BD} = \frac{1.2\text{ cm}}{0.8\text{ cm}} = 1.5$

## REAL AND APPARENT DEPTHS

When an object is seen from other medium, we don't see its actual depth or height. The depth we see is called apparent depth and the actual depth is called the real depth.

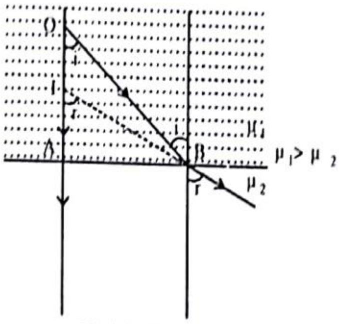



Fig. 1.52 (a)

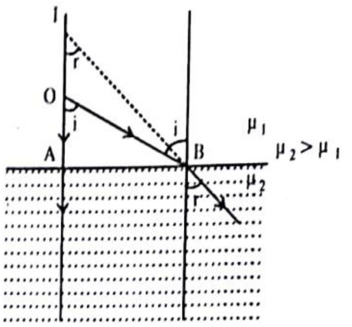



Fig. 1.52(b)

Let us consider an object $O$ placed in a medium of refractive index $\mu_1$. It is being observed by an observer in other medium of refractive index $\mu_2$.

Two rays $OA$ and $OP$ are made incident on the interface separating the two media where they get refracted. $OA$ passes through second medium undeviated as it falls normally. When the refracted rays are produced backward, they meet at $I$ producing virtual image of $O$ there. If $\mu_1 > \mu_2$ [Fig. 152 (a)], i.e., observer is in rarer medium, the image is formed at a distance less than the object from the observer. In other words, the image shifts towards the observer.

If $\mu_1 < \mu_2$ [Fig. 1.52 (b)], i.e., observer is in denser medium, the image is formed at a distance greater than the distance of the object from the observer. That is, the image shifts away from the observer.

Let us now calculate the shift $OI$ ($= \Delta t$).

If $i$ and $r$ are small,

$$\sin i \approx \tan i = \frac{AB}{OA} \qquad \text{and} \qquad \sin r \approx \tan r = \frac{AB}{IA}$$

By Snell's law,

$$\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1} \Rightarrow \frac{AB}{OA} \times \frac{IA}{AB} = \frac{\mu_2}{\mu_1} \Rightarrow \frac{IA}{OA} = \frac{\mu_2}{\mu_1}$$

Clearly, $IA$ = Apparent depth of object

$OA$ = Real depth of object

$$\therefore \frac{\text{Apparent Depth}}{\text{Real Depth}} = \frac{\mu_2}{\mu_1}$$

**Case I :** If $\mu_1 = \mu$ and $\mu_2 = 1$ (for air), then

$$\frac{AI}{AO} = \frac{\text{Apparent Depth}}{\text{Real Depth}} = \frac{1}{\mu} \qquad .....(1)$$

$$\Rightarrow \boxed{\mu = \frac{\text{Real Depth}}{\text{Apparent Depth}}}$$

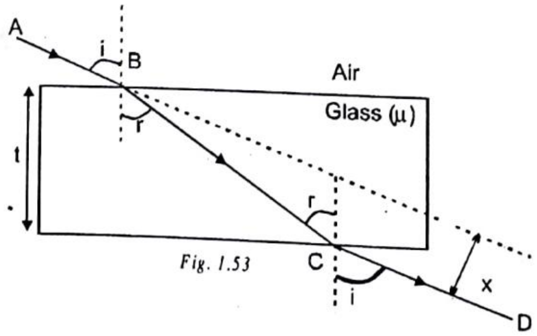



Fig. 1.53

Now, shift in image ($\Delta t$) $= OI$

$$= AO - AI = \left(\frac{AO - AI}{AO}\right)AO = \left(1 - \frac{AI}{AO}\right)AO$$

or $$\boxed{\Delta t = \left(1 - \frac{1}{\mu}\right)t}, \quad \text{From (1)}$$

where $t = AO$ = thickness of the medium in which object is placed.

**NOTE :** If the object is placed in a medium which consists of a number of media of refractive indices $\mu_1, \mu_2, \mu_3, .......$ and thickness $t_1, t_2, t_3, .......$ respectively, then

Virtual depth (AI) $= \frac{t_1}{\mu_1} + \frac{t_2}{\mu_2} + \frac{t_3}{\mu_3} + ..............$

Virtual displacement (OI) $= t_1\left(1-\frac{1}{\mu_1}\right) + t_2\left(1-\frac{1}{\mu_2}\right) + t_3\left(1-\frac{1}{\mu_3}\right) + ..............$

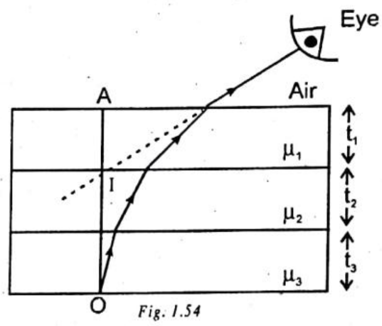


Fig. 1.54

**Case II :** If $\mu_1 = 1$ (for air) and $\mu_2 = \mu$, then

$$\frac{AI}{AO} = \frac{\text{Apparent Depth}}{\text{Real Depth}} = \mu \qquad .....(2)$$

$\therefore$ Shift in image $= OI = AI - AO$

$$= \left(\frac{AI - AO}{AO}\right)AO = \left(\frac{AI}{AO} - 1\right)AO$$

$\Rightarrow \quad \boxed{\Delta t = (\mu - 1)t}$

**Case III : When object & observer both are in rarer medium.**

Let observer is in air & object is at a point $O$ in air, as shown in figure.

A glass is there in between observer & object. Image forms at point $I$.

Refractive index of glass is $\mu$,

Virtual displacement $= OI = \left(t - \frac{1}{\mu}\right)$

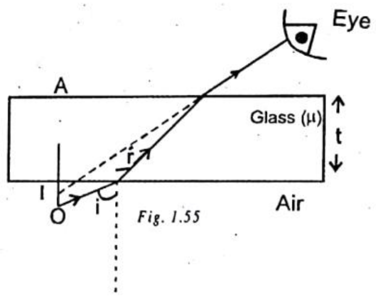


Fig. 1.55

**ILLUSTRATION–1.26**

When a glass slab is placed on a dot on a paper, it appears displaced by 4 cm, viewed normally. What is the thickness of slab if the refractive index is 1.5.

**SOLUTION :**

We know that Displacement $= t\left(1-\frac{1}{\mu}\right)$ So $4 = t\left(1-\frac{1}{\mu}\right)$

$$t = \frac{\mu \times 4}{\mu - 1} = \frac{1.5 \times 4}{1.5 - 1} = 12\,\text{cm}$$

## LENS

A lens is a piece of transparent material with two refracting surfaces such that at least one is curved and refractive index of used material is different from that of the surroundings.

A thin spherical lens with refractive index greater than that of surrounding behaves as a convergent or convex lens i.e. converges parallel rays. Its central (i.e. paraxial) portion is thicker than marginal one.

However if the central portion of a lens (with $\mu_L > \mu_M$) is thinner than marginal, it diverges parallel rays and behaves as a divergent or a concave lens. This is how we classify and identify convergent and divergent lenses.

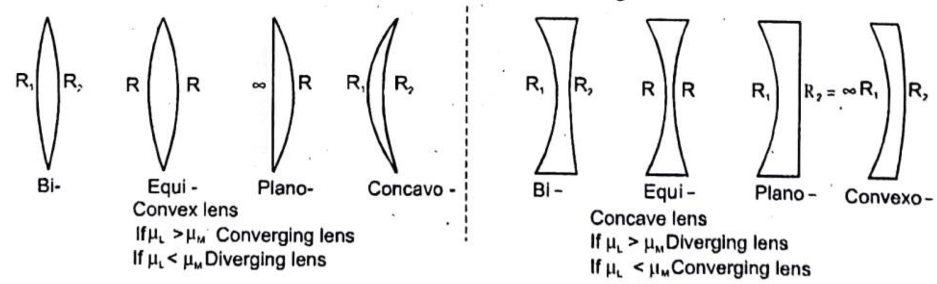


Fig. 1.56 (a) Fig. 1.56 (b)

## TERMS RELATED TO THIN SPHERICAL LENS

**Optical centre ($O$)** - $O$ is a point for a given lens through which any ray passes undeviated.

**Principal Axis ($C_1C_2$)** - $C_1\,C_2$ is a line passing through optical centre and perpendicular to the lens. The centre of curvature of curved surface always lie on the principal axis (as in a sphere is always perpendicular to surface)

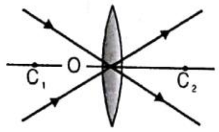



Fig. 1.57 (a)

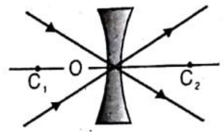



Fig. 1.57 (b)

**Principal Focus** - A lens has two surfaces and hence two focal points first focal point is an object on the principal axis for which image is at infinity while

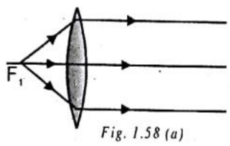



Fig. 1.58 (a)

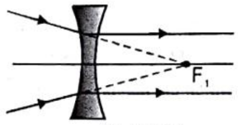



Fig. 1.58 (b)

Second focal point is an image point on the principal axis for which object is at infinity.

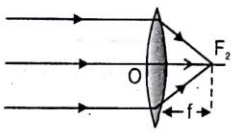



Fig. 1.59 (a)

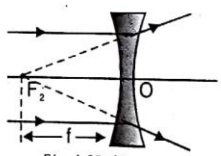



Fig. 1.59 (b)

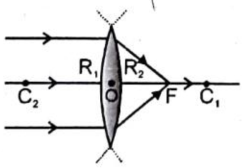
**Focal Length ($f$)** - It is defined as the distance between optical centre of a lens and the point where the parallel beam of light converges or appear to converge i.e., focus.

**Aperture** - In reference to lens, aperture means to effective diameter of its light transmitting area so that brightness i.e. intensity of image formed by a lens which depends on the light passing through the lens will depend on the square of aperture i.e.

$$I \propto (\text{aperture})^2$$

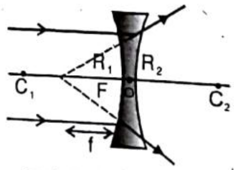
## SIGN - CONVENTION

1. Whenever and where possible, rays of light are taken to travel from left to right.
2. Transverse distances are measured from optical centre and are taken to be positive while those below it negative.
3. Longitudinal distances are measured from optical centre and are taken to be positive if in the direction of light propagation and negative if opposite to it e.g., according to our convention the sign of $R_1$, $R_2$ and f are given the following two cases




$R_1(=OC_1)$=Positive
$R_2(=OC_2)$=Negative
f(=OF)=Positive

Fig. 1.60 (a)




$R_1(=OC_1)$=Negative
$R_2(=OC_2)$=Positive
f(=OF)=Negative

Fig. 1.60 (b)

While using the sign convention it must be kept in mind that -

(i) To calculate an unknown quantity the known quantities are substituted with sign in a given formula.

(ii) In the result, sign must be interpreted as there are number of sign conventions and same sign has different meaning in different conventions.

## RULES FOR IMAGE FORMATION

In order to locate the image formed by a lens graphically following rules are adopted -

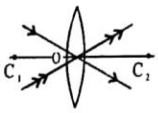



Fig. 1.61 (a)

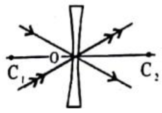



Fig. 1.61 (b)

1. A ray passing through optical centre proceeds undeviated through the lens (by definition of optical centre).
2. A ray passing through first focus or directed towards it, after refraction from the lens becomes parallel to the principal axis (by definition of $F_1$).
3. A ray passing parallel to the principal axis after refraction through the lens passes or appear to pass through $F_2$ (by definition of $F_2$).
4. Only two rays from the same point of an object are needed for image formation and the point where the rays after refraction through the lens intersect or appear to intersect is the image of the object. If they actually intersect each other the image is real and if they appear to intersect the image is said to be virtual.

## CHECK Point

- **The diagram below shows the refracted ray BC through a concave lens and its foci marked as $F_1$ and $F_2$. Complete the diagram by drawing the corresponding incident ray.**

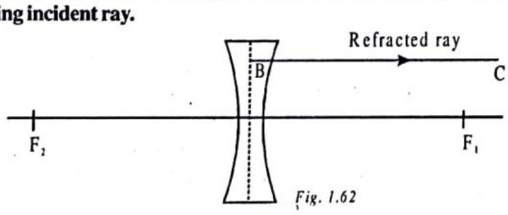



Fig. 1.62

### SOLUTION

Figure shows the refracted ray parallel to the principal axis. Therefore the incident ray must be travelling towards the first focus $F_1$. Thus to find the incident ray, $F_1$ is joined to the starting point B of the refracted ray and produced as shown in figure. *AB* is the incident ray.

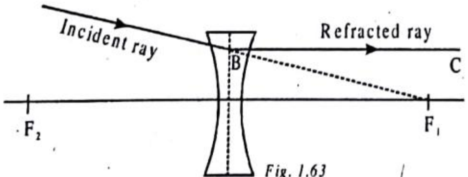



Fig. 1.63

## CHECK Point

- **The diagram shows an object *OA* and its image IB formed by a lens. Complete the ray diagram and locate the focus of the lens by labelling as *F*. State whether the lens is convex or concave ?**

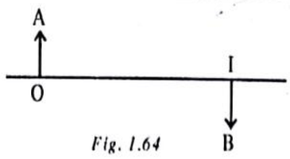



Fig. 1.64

### SOLUTION

To complete the diagram. The completed ray diagram is given below.

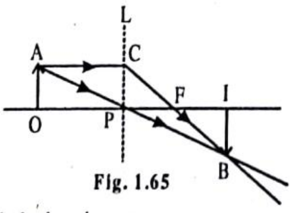
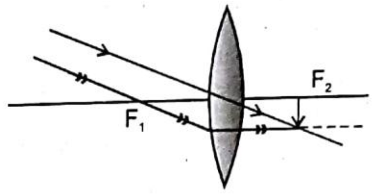
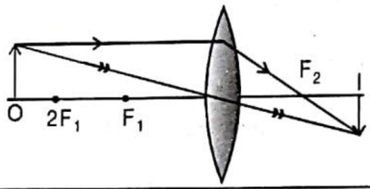
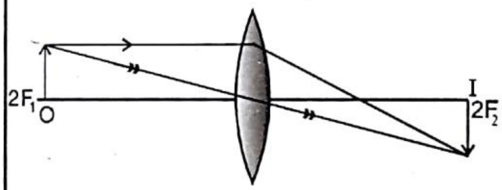
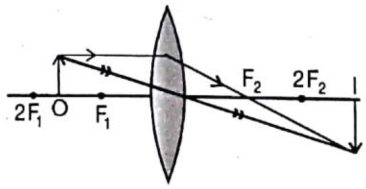
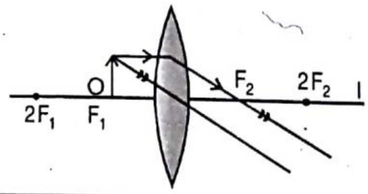
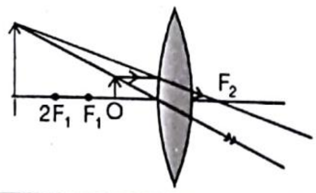



Fig. 1.65

Since the image is inverted and magnified, the lens is convex.

## IMAGE FORMATION BY A LENS

(a) For convergent or Convex Lens

| Position of object | Details of Image | Figure |
|---|---|---|
| At infinity | Real, inverted, diminished ($m << -1$), At F |  |
| Between infinity and 2F | Real, inverted, diminished ($m < -1$), Between F and 2F |  |
| At 2F | Real, inverted, equal in size, ($m = -1$) At 2F |  |
| Between 2F and F | Real, inverted, enlarged ($m > -1$), Between 2F and ∝ |  |
| At F | Real, inverted, enlarged ($m >> -1$), At infinity |  |
| Between Focus & Pole | Virtual, erect, enlarged ($m > +1$), Between ∞ and Object, on same side of object |  |

**(b) For Divergent or Concave lens**

If object is at infinity image will be formed at focus.

If object is, in front of lens, image will be virtual and erect.

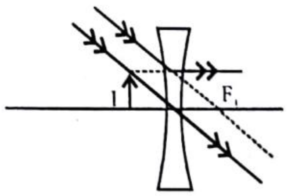



Fig. 1.66 (a)

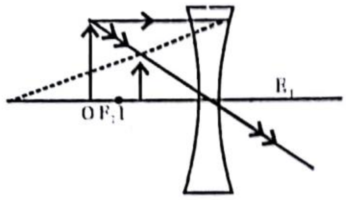



Fig. 1.66 (b)

## LENS FORMULA

If an object is placed at a distance $u$ from the optical centre of a lens and its images is formed at a distance $v$ (from the optical centre) and focal length of this lens is $f$ then $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$ this relationship is known as Lens formula

**Proof :** Consider an object $AB$ placed beyond $2F$ infront of a convex lens. A real, inverted and smaller image is formed between $F$ and $2F$ on the other side of the lens. Applying sign convention, we obtain.

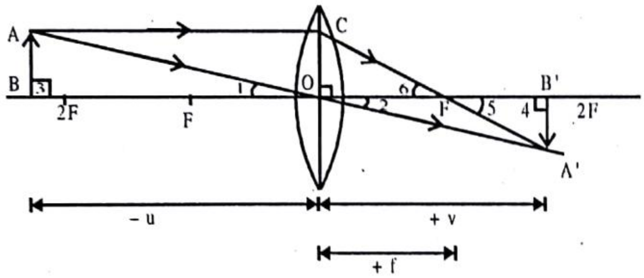



Fig. 1.67

(object distance) $OB = -u$

(Image distance) $OB' = +v$

(Focal Length) $OF = +f$

In $\Delta ABO$ and $\Delta A'B'O$,

$\angle 1 = \angle 2$ (Vertically Opposite angles)

$\angle 3 = \angle 4$ (Each 90°)

$\therefore \angle BAO \sim \angle B'A'O$ (By $AA$ similarity).

Therefore, $\Delta ABO$ and $\Delta A'B'O$ are equiangular and hence they are similar.

$$\therefore \frac{A'B'}{AB}=\frac{OB'}{OB}=\frac{+v}{-u} \Rightarrow \frac{A'B'}{AB}=\frac{+v}{-u} \quad \text{.........(1)}$$

Now $\Delta OCF$ and $\Delta A'B'F$ are also equiangular, hence similar.

In particular, $\frac{A'B'}{OC}=\frac{FB'}{OF}$

But $OC = AB$.

$$\therefore \frac{A'B'}{AB}=\frac{FB'}{OF}$$

Since All distances are measured from optical centre, therefore,

$$\frac{A'B'}{AB}=\frac{FB'}{OF}=\frac{OB'-OF}{OF}=\frac{+v-(+f)}{+f}=\frac{v-f}{f} \quad \text{...........(2)}$$

Now comparing eq. (1) and (2), $\frac{+v}{-u} = \frac{v-f}{f} \Rightarrow fv = -uv + fu$

Dividing both sides by $uvf$, $\frac{1}{u} = -\frac{1}{f} + \frac{1}{v} \Rightarrow \frac{1}{f} = \frac{1}{v} - \frac{1}{u}$

Similarly, we can prove the lens formula for a concave lens.

**ILLUSTRATION–1.27**

Two converging lenses with focal lengths 15 cm and 25cm are placed 18cm apart. An object is located 8.0 cm to the left of the 15cm focal length lens. Where is the final image formed ?

**SOLUTION :**

Find the image location for the first lens using the thin lens equation.

$$\frac{1}{v_1} = \frac{1}{f_1} - \frac{1}{u_1} = \frac{1}{15\text{cm}} - \frac{1}{8.0\text{cm}} \qquad \text{which gives } v_1 = -17\text{cm}$$

This image forms the object of the second lens located 17 cm + 18 cm = 35 cm away. The thin lens equation gives for the second lens

$$\frac{1}{v_2} = \frac{1}{f_2} - \frac{1}{u_2} = \frac{1}{25\text{ cm}} - \frac{1}{35\text{ m}} \qquad \text{which gives } v_2 = 87.5\text{ cm}$$

The final image lies 87.5 cm to the right of the second lens (25 cm) lens.

**ILLUSTRATION–1.28**

A converging lens is used to read the small print in a contract. The lens is held 9.0 cm from the print and produces a magnification of +2.5. What is the focal length of the lens ?

**SOLUTION :**

The fine print serves as the object for the lens $u = 9.0$ cm. The image distance is then

$$v = -mu = -(2.5\text{ cm})(9.0\text{ cm}) = -22\text{ cm}$$

The thin lens equation gives $\frac{1}{f} = \frac{1}{u} + \frac{1}{v} = \frac{1}{9.0\text{ cm}} + \frac{1}{(-22\text{ cm})}$

so $f = +15$ cm.

## POWER OF A LENS

If focal length of a lens is measured in metre ($m$) then its reciprocal gives the power ($P$) of the lens. That is,

$$P = \frac{1}{f(\text{in m})}$$

The unit of power is diopter ($D$).

**CHECK Point**

- **Diving masks often have lenses built into the glass for divers who do not have perfect vision. This allows the individual to dive without the necessity for glasses, because the lenses in the faceplate perform the necessary refraction to provide clear vision. Normal glasses have lenses that are curved on both the front and rear surfaces. The lenses in a diving mask faceplate often only have curved surfaces on the *inside* of the glass. Why is this design desirable?**

**SOLUTION**

The main reason for curving only the inner surface of the lenses in the diving mask faceplate is so that the diver can see clearly when looking at objects straight ahead while underwater *and* in the air. Consider light rays approaching the mask along a normal to the plane of the faceplate. If curved surfaces were on both the front and the back of the diving lens on the faceplate, refraction would occur at each surface. The lens could be designed so that these two refractions would give clear vision while the diver is in air. When the diver is underwater, however, the refraction between the water and the glass at the first interface is now different because the index of refraction of water is different from that of air. Thus, the vision would not be clear underwater.

By making the outer surface of the lens flat, light is not refracted at normal incidence to the faceplate at the outer surface *in either air or water*—all of the refraction occurs at the inner glass–air surface. Thus, the same refractive correction exists in water and in air, and the diver can see clearly in both environments.

**ILLUSTRATION–1.29**

A convex lens of 1.20 cm is placed in contact with concave lens of 1. 60 cm. Calculate : (a) power of each of the lens (b) power of combination (c) focal length of combination (d) nature of combination.

**SOLUTION :**

(a) Power of convex lens $= \frac{100}{20} = +5D$

power of concave lens $= \frac{100}{60} = -1.67\ D$

(b) Power of combination $P = P_1 + P_2 = (+5D) + (-1.67D) = +3.33\ D$

(c) Focal length of combination

$$f(\text{in cm}) = \frac{100}{P} = \frac{100}{3.33} = +30.0\ \text{cm}$$

(d) As power of combination is positive, therefore, combination behaves like a convex lens.

**ILLUSTRATION–1.30**

A doctor has prescribed a corrective lens of power +1.5 D. Find the focal length of the lens. Is the prescribed lens diverging or converging?

**SOLUTION :**

$$P = +1.5D$$

$$f = \frac{100}{P}\ \text{cm} = \frac{100}{1.5} = \frac{1000}{15} = +66.67\ \text{cm} = +0.67\text{m}$$

So the focal length is + *ve*, it is convex lens. Hence it is a converging lens.

Magnification produced by a lens.

If a thin object of linear size $O$ situated vertically on the axis of a lens at a distance $u$ from the optical centre and its image of size $I$ is formed at a distance $v$ (from the optical centre) then magnification (transverse) is defined as

$$m = \frac{I}{O} = \frac{v}{u}$$

$m$ can be negative or positive.

Negative magnification implies that image is inverted with respect to object while positive magnification means that image is erect with respect to object.

**Other formulae of magnification**

$$m = \frac{f}{f+u},$$

$$m = \frac{f-v}{f}$$

For real extended object, if the image formed by a single lens in inverted (i.e., m is negative) it is always real and the lens is convergent i.e., convex.

**ILLUSTRATION–1.31**

An object is placed at a distant of 1.50 m from a screen and a convex lens placed in between produces an image magnified 4 times on the screen. What is the focal length and the position of the lens.

**SOLUTION :**

The information given in the question ray diagram. It is given that

$$m = \frac{I}{O} = -4$$

Let lens is placed at a distance of $x$ from the object. Then
$u=-x$, and $v=(1.5-x)$

using $m=\frac{v}{u}$, we get $-4=\frac{1.5-x}{-x}$

or $4x=1.5-x$ or $5x=1.5$
Thus $x=0.3$ metre
The lens is placed at a distance of 0.3 $m$ from the object (or 1.20 $m$ from the screen)

For focal length, we may use $m=\frac{f}{f+u}$

or $-4=\frac{f}{f+(-0.3)}$ or $-4f+1.2=f$ or $5f=1.2$ Thus $f=\frac{1.5}{5}=0.24$
The focal length is 0.24 $m$ (or 24 cm)

**ILLUSTRATION 1.32**

A lens placed at a distance of 20 cm from an object produces a virtual image 2/3 the size of the object. Find the position of the image, kind of lens and its focal length.

**SOLUTION:**

Virtual image means, $I$ is positive and it is given that $I=\frac{2}{3}O$. Thus, $m=+\frac{2}{3}$

Further because $u=-20$ cm (given), using $m=\frac{f}{f+u}$

we get, $\frac{2}{3}=\frac{f}{f+(-20)}$ or $f=-40\,\text{cm}$

The $f$ is negative, thus the lens is a concave lens. Again using $m=\frac{v}{u}$

we get $\frac{2}{3}=\frac{v}{-20}$ or $v=-\frac{2}{3}=-1.33$ cm
The virtual image is on the same side of the object.

## LENS MAKER FORMULA

This formula gives a relation among the focal length ($f$), the efractive index of a lens with respect to the medium in which it is placed $({}_m\mu_\ell)$ and its radii of curvatures ($R_1$ and $R_2$). This formula is expressed as

$$\frac{1}{f}=({}_m\mu_\ell-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right) \quad \text{or} \quad \frac{1}{f}=\left(\frac{{}_a\mu_\ell}{{}_a\mu_m}-1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

where, ${}_a\mu_\ell$ = refractive index of lens with respect to air.

${}_a\mu_m$ = refractive index of lens with respect to air.

$R_1$ = radius of curvature of first surface of lens.

$R_2$ = radius of curvature of second surface of lens.

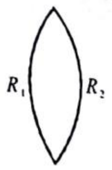
If lens is placed in air, then

${}_a\mu_m=1$ and ${}_a\mu_\ell=\mu$ (say)

$$\therefore \frac{1}{f}=(\mu-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

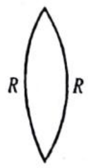
# Knowledge ENHANCER

**Sign convention for $R_1$ and $R_2$ :** Observe the sign convention for $R_1$ and $R_2$ in following figures



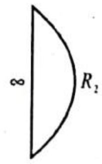

$R_1 = +R_1, R_2 = -R_2$

$\therefore \quad \frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$



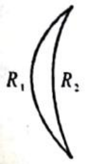

$R_1 = R, R_2 = -R$

$\frac{1}{f} = (\mu - 1)\frac{2}{R}$



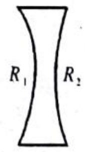

$R_1 = \infty, R_2 = -R$

$\frac{1}{f} = (\mu - 1)\left(\frac{1}{\infty} + \frac{1}{R}\right) = \left(\frac{\mu - 1}{R}\right)$



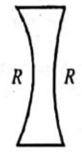

$R_1 = +R_1, R_2 = +R_2$

$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$




$R_1 = -R_1, R_2 = +R_2$

$\frac{1}{f} = -(\mu - 1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$

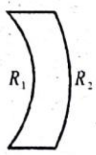



$R_1 = -R, R_2 = +R$

$\frac{1}{f} = -(\mu - 1)\frac{2}{R}$


$R_1 = -R, R_2 = \infty$

$\frac{1}{f} = -(\mu - 1)\frac{1}{R}$




$R_1 = -R_1, R_2 = -R_2$

$\frac{1}{f} = -(\mu - 1)\left(\frac{1}{R_2} - \frac{1}{R_1}\right)$

*In case of sun-goggles, the radii of curvature of two surfaces are equal with centre on same side i.e.,*

$R_1 = R_2 = +R$

*So* $\frac{1}{f} = (\mu - 1)\left[\frac{1}{+R} - \frac{1}{+R}\right] = 0$

*i.e.,* $f = \infty$ and $P = (1/f) = 0$

*This is why sun-goggles have no power or infinite focal length. Same is true for a transparent sheet with the difference that here*

$R_1 = R_2 = \infty$

## COMBINATION OF LENSES

**Case I : When two thin lenses are in contact.**

In case of two thin lenses in contact if the first lens of focal length $f_1$ forms the image $I_1$ (of an object) at a distance $v_1$ from it,

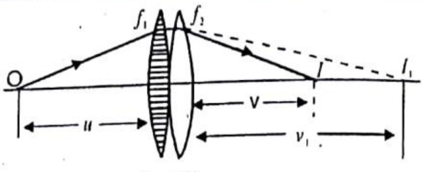


Fig.1.68

$$\frac{1}{v_1}-\frac{1}{u}=\frac{1}{f_1}$$

now the image $I_1$ will act as object for second lens and if the second lens forms image $I$ at a distance $v$ from it,

$$\frac{1}{v}-\frac{1}{v_1}=\frac{1}{f_2}$$

Adding above equations $\frac{1}{v}-\frac{1}{u}=\frac{1}{f_1}+\frac{1}{f_2}$ or $\frac{1}{v}-\frac{1}{u}=\frac{1}{F}$ with $\frac{1}{F}=\frac{1}{f_1}+\frac{1}{f_2}$

i.e. the combination behaves as a single lens of equivalent focal length $F$ given by

$$\frac{1}{F}=\frac{1}{f_1}+\frac{1}{f_2} \text{ or } P=P_1+P_2$$

**Case II : When two thin lenses are separated by a certain distance.**

If the two thin lens are separated by a distance $d$ apart, then $F$ is given by

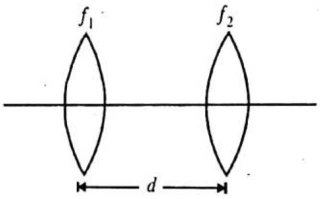


Fig. 1.69

$$\frac{1}{F}=\frac{1}{f_1}+\frac{1}{f_2}-\frac{d}{f_1f_2}$$

so $P=P_1+P_2-P_1P_2d.$

**NOTE:** (1) If two thin lenses of equal focal length but of opposite nature (i.e. one convergent and other divergent) are put in contact, the resultant focal length of the combination will be

$\frac{1}{F}=\frac{1}{+f}+\frac{1}{-f}=0$ i.e, $F=\infty$ and $P=0$ i.e., the system will behave as a plane glass plate.

(2) If two thin lens of same nature are put in contact then as

$$\frac{1}{F}=\frac{1}{f_1}+\frac{1}{f_2}$$

$\frac{1}{F}>\frac{1}{f_1}$ and $\frac{1}{F}>\frac{1}{f_2}$ i.e. $F<f_1$ and $F<f_2$

i.e. the resultant focal length will be lesser than smallest individual.

(3) If two thin lenses of opposite nature with different focal lengths are put in contact the resultant focal length will be of same nature as that of the lens of shorter focal length but its magnitude will be more than that of shorter focal length. If a lens of focal length f is divided into two equal parts as in figure (A)

each part has a focal length f′ then as $\frac{1}{f}=\frac{1}{f'}+\frac{1}{f'}$ $\qquad f'=2f$

i.e. each part have focal length 2f now if the se parts are put in contact as in (B) or (C), the resultant focal length of the combination will be $\frac{1}{F}=\frac{1}{2f}+\frac{1}{2f}$ i.e. $F=f(=\text{initial value})$

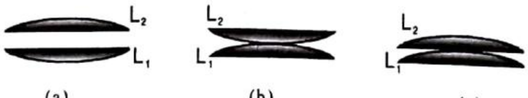


Fig. 1.70

**ILLUSTRATION–1.33**

A convex lens of focal length 10.0 cm is placed in contact with a convex lens of 15.0 cm focal length. What is the focal length of the combination.

**SOLUTION:**

For combination of lenses

$$\frac{1}{f}=\frac{1}{f_1}+\frac{1}{f_2}=\frac{1}{10}+\frac{1}{15}=\frac{25}{150}=\frac{1}{6}$$

Therefore, $f = 6\,\text{cm}$

**ILLUSTRATION–1.34**

Ten identical converging thin lenses, each of focal length 10 cm, are in contact. What is the power of the combined lens.

**SOLUTION:**

For thin lenses in contact

$$P=P_1+P_2+\ldots\ldots\ldots\ldots$$

$$=10P_1=\frac{10\times100}{10}=100\,\text{D}$$

## Knowledge ENHANCER

### SILVERING OF LENS

A lens has two surfaces. If one of the surfaces is silvered, the lens behaves as a mirror. The mechanism of the image formation can be understood in brief as given below.

Light from the object falls on the lens which produces a virtual image $I_1$. This image acts as object for the silvered surface (which acts as a mirror) and a second virtual image $I_2$ is formed. Finally, this image acts as object for the lens and final image $I_3$ is formed. Thus, refraction takes place two times at the lens and reflection takes one time at the mirror.

Thus, on silvering the lens behaves as a mirror of focal length $F$ given by

$$\frac{1}{F}=\frac{2}{F_\ell}+\frac{1}{F_m} \qquad \ldots\ldots(1)$$

where $F_\ell$ = focal length of lens from which refraction take place two times.

$F_m$ = focal length of mirror from which reflection takes place one time.

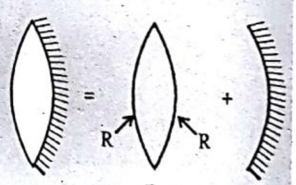



Fig. 1.71 (a)

**Case I : When a double convex lens is silvered.**

Clearly, $F_m=\frac{R}{2}$

Also, by lens maker formula,

$$\frac{1}{F_\ell}=(\mu-1)\left(\frac{1}{R}+\frac{1}{R}\right)=(\mu-1).\frac{2}{R}$$

$$\therefore \quad F_\ell=\frac{R}{2(\mu-1)}$$

Putting the values of $F_m$ and $F_\ell$ in (1), we get

$$\frac{1}{F}=\frac{2\times2(\mu-1)}{R}+\frac{2}{R}=\frac{2(2\mu-1)}{R}$$

$$\therefore \quad \boxed{F=\frac{R}{2(2\mu-1)}}$$

**Case II : When a planes convex lens is silvered.**

(i) If curved surface is silvered

In this case,

$$F_m = \frac{R}{2} \quad \text{and} \quad F_\ell = \frac{R}{\mu - 1}$$

$$\therefore \quad \boxed{F = \frac{R}{2\mu}}$$

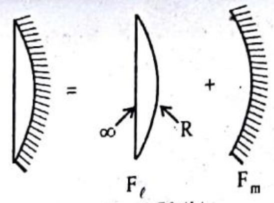



Fig. 1.71 (b)

(ii) **If plane surface is silvered.**

In this case, $F_m = \infty$ ($\because R = \infty$)

and $F_\ell = \dfrac{R}{\mu - 1}$

$$\therefore \quad \boxed{F = \frac{R}{2(\mu - 1)}}$$

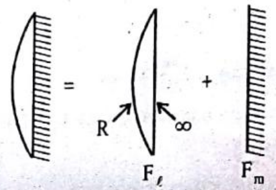



Fig. 1.71 (c)

**ILLUSTRATION – 1.35**

The radius of curvature of a thin plano-convex lens is 10 cm (of curved surface) and the refractive index is 1.5. If the plane surface is silvered, then it behaves like a concave mirror of focal length

(a) 10 cm (b) 15 cm (c) 20 cm (d) 5 cm

**SOLUTION :**

(a) The silvered plano convex lens behaves as a concave mirror; whose focal length is given by

$$\frac{1}{F} = \frac{2}{f_1} + \frac{1}{f_m}$$

If plane surface is silvered

$$f_m = \frac{R_2}{2} = \frac{\infty}{2} = \infty$$

$$\therefore \frac{1}{f_1} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = (\mu - 1)\left(\frac{1}{R} - \frac{1}{\infty}\right) = \frac{\mu - 1}{R}$$

$$\therefore \frac{1}{F} = \frac{2(\mu - 1)}{R} + \frac{1}{\infty} = \frac{2(\mu - 1)}{R}$$

$$F = \frac{R}{2(\mu - 1)}$$

Here, $R = 10$ cm, $\mu = 1.5$

$$\therefore F = \frac{10}{2(1.5 - 1)} = 10\text{cm}$$

Fig. 1.72

**ILLUSTRATION – 1.36**

A luminous object is placed at a distance of 30 cm from the convex lens of focal length 20 cm. On the other side of the lens, at what distance from the lens a convex mirror of radius of curvature 10 cm be placed in order to have an upright image of the object coincident with it?

(a) 12 cm (b) 30 cm (c) 50 cm (d) 60 cm

**SOLUTION :**

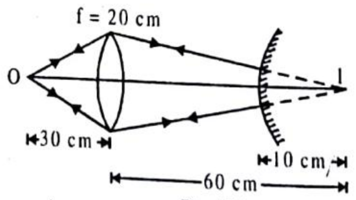



Fig. 1.73

(c) For the lens, $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$; $\frac{1}{v} - \frac{1}{-30} = \frac{1}{20} \Rightarrow v = 60$ cm

Coincidence is possible when the image is formed at the centre of curvature of the mirror. Only then the rays refracting through the lens will fall normally on the convex mirror and retrace their path to form the image at O. So, the distance between lens and mirror = 60 – 10 = 50 cm.

## CHROMATIC ABERRATION

The image of a white object (or illuminated by white light) formed by a lens is usually coloured and blurred. This defect of the image produced by a lens is called 'chromatic aberration'. This defect arises because the refractive index of the material of the lens and hence the focal length of the lens, is different for different colours of light for a thin lens. Smaller the focal length of a lens (i.e. greater the power), smaller is the chromatic aberration in the lens.

## SOME OTHER PROPERTIES OF LIGHT

As we know light shows dual nature – the nature of a particle in some cases and the nature of a wave in some other. When light behaves as a wave, it shows the following characteristics –

(i) Interference
(ii) Diffraction
(iii) Polarisation etc.

When light behaves as a particle, it performs phenomenon like photoelectric effect.

## INTERFERENCE OF LIGHT

The colours in soap bubbles and oil slicks are due to this property of light. When two light waves of exactly same frequency travels in a medium, in the some direction simultaneously then due to their superposition, the intensity of light is maximum at some points while the intensity is minimum at some other points. This phenomenon is called interference of light. It is of two types :

(i) Constructive interference and
(ii) Destructive interference

When the waves meet a point with same phase, constructive interference is obtained at that point. Hence, at that point bright spot of light is seen.

But when the waves meet a point with opposite phase, destructive interference is obtained at that point. Hence, at that point dark spot of light is seen.

## YOUNG'S DOUBLE SLIT EXPERIMENT

Fringes are produced by **interference**, which we discussed. Constructive and destructive interference is reviewed in fig. 1.74. We see that the addition, or *superposition,* of a pair of identical waves in phase with each other produces a wave of the same frequency but with twice the amplitude. If the waves are exactly one-half wavelength out of phase, their superposition results in complete cancellation. If they are out of phase by order other amounts partial cancellation occurs

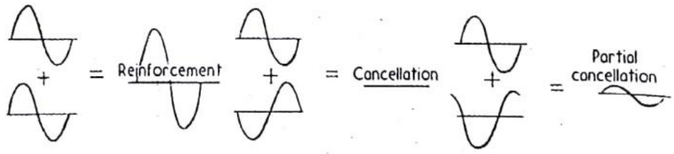



*Fig.1.74. Wave interference*

In 1801, the wave nature of light was convincingly demonstrated when the British physicist and physician Thomas Young performed his now famous interference experiment. Young found that light directed through two closely spaced pinholes recombined to produce fringes of brightness and darkness on a screen behind. The bright fringes of light resulted from light waves from the two holes arriving crest to crest, while the dark areas resulted from light waves arriving trough to crest. Fig.1.75 shows Young's drawing of the pattern of superimposed waves from the two sources. His experiment is now done with two closely spaced slits instead of with pinholes, so the fringe patterns are straight lines. (in Fig. 1.76)

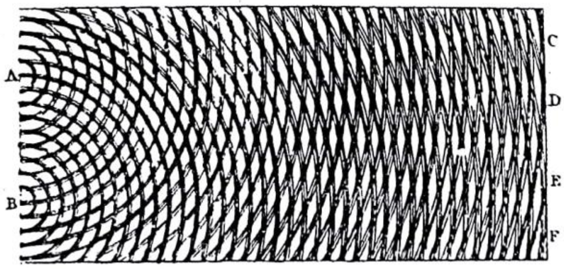



*Fig.1.75. Thomas Young's original drawing of a two-source interference pattern. Letter C, D, E and F mark regions of destructive interference*

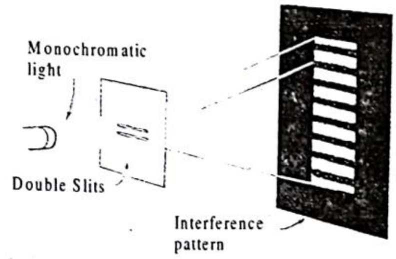



*Fig.1.76 : When monochromatic light passes through two closely spaced slits, a striped interference pattern is produced.*

We see in figures and how the series of bright and dark lines results from the different path lengths from the slits to the screen. For the central bright fringe, the paths from each slit are the same length, and the waves arrive in phase and reinforce each other. The dark fringes on either side of the central fringe result from one path being longer (or shorter) by one-half a wavelength where the wave arrive half a wavelength where the wave arrive half a wavelength where the wave arrive half a wavelenght out of phase. The other sets of dark fringes occur where the paths differ by odd multiples of one-half wavelength : 3/2, 5/2 so on.

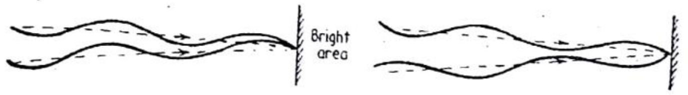



*Fig.1.77 (a). Bright fringes occur when waves from both slits arrive in phase; dark areas result from the overlapping of waves that are out of phase.*

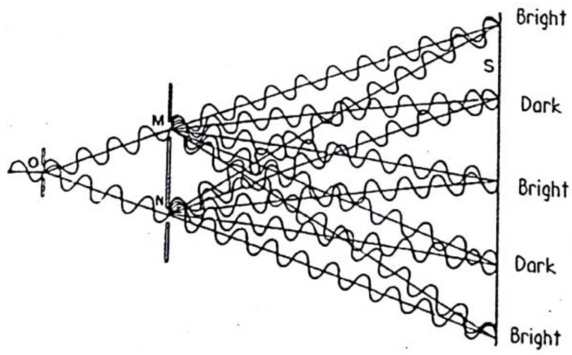



*Fig.1.77(b) : Light from O passes through slits M and N and produces an interference pattern on the screen S.*

## CHECK Point

- **If the double slits were illuminated with monochromatic red light, would the fringes be more widely or more closely spaced than if they were illuminated with monochromatic blue light?**
  **Why is it important that monochromatic (single-frequency) light be used ?**

### SOLUTION

They would be more widely spaced. Can you see in Fig.1.77 (b), that a slightly longer path– and therefore a slightly more displaced path– from the entrance slit to the screen would result for the longer waves of red light ?

If light of various wavelengths were diffracted by the slits, dark fringes for one wavelength would be filled in with bright fringes for another, resulting in no distinct fringe pattern. If you haven't seen this, be sure to ask your instructor to demonstrate it.

## DIFFRACTION OF LIGHT

The wavelength of light is of the order of angstroms. So, when light waves encounter obstacles of very small sizes, the light waves bend around the edges of the obstacle and travel. This is known as diffraction of light. It is due to the diffraction of light that a sharp shadow of an object cannot be obtained on any screen placed behind it. Due to diffraction, light bends and travels into the region of geometrical shadow of the object and thus complete darkness is not found in the shadow. The brightness of light gradually decreases towards complete darkness as we go gradually into the geometrical shadow of the obstacle.

## POLARISATION OF LIGHT

An ordinary source of light such as bulb consists of a large number of waves emitted by atoms or molecules in all directions symmetrically. Such light is called unpolarized light (Fig. 1.78 (a))

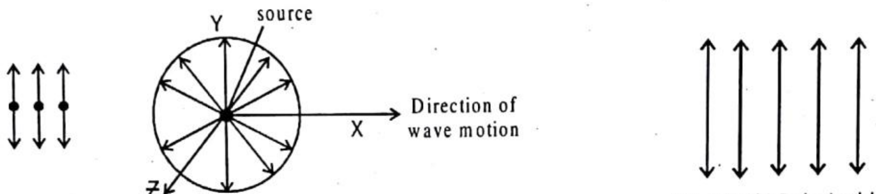



Fig.1.78 (a) Unpolarised light

Fig.1.78 (b) Polarised light

If we confine the direction of wave vibration of electric vector in one direction (with the help of polaroids or Nicol prism) perpendicular to the direction of wave propagation, then such type of light is called plane polarised or linearly polarised. The phenomenon by which, we restrict the vibrations of wave in a particular direction (fig.1.78 (b). Perpendicular to direction of wave propagation is called polarisation.

## MISCELLANEOUS SOLVED EXAMPLES

**1. An object is situated at a distance of $f/2$ from a convex lens of focal length $f$. Find the distance of image.**

**Sol.** For a spherical lens, $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$

For convex lens, $u=-f/2$ and $f$ is + ve

$\therefore \quad \frac{1}{v}=\frac{1}{f}+\frac{1}{u}=+\frac{1}{f}-\frac{2}{f}=-\frac{1}{f} \quad \therefore \quad v=-f$

**2. An object of length 1 cm is placed at a distance of 15 cm from a concave mirror of focal length 10 cm. Find the nature and size of the image.**

**Sol.** Given u = – 15 cm, $f$ = – 10 cm, O = 1 cm

$\frac{1}{v}+\frac{1}{u}=\frac{1}{f},\ \frac{1}{v}=\frac{1}{f}-\frac{1}{u}=\frac{1}{-10}-\frac{1}{-15}$

$\therefore\ v=-30$ cm $\qquad \frac{I}{O}=-\frac{v}{u}=-\frac{-30}{-15}=-2$

$I=-2\times 1=-2$ cm $\qquad$ Image is inverted and on the same side (real) of size 2 cm.

**3. A biconvex lens whose both the surfaces have same radii of curvature has a power of 5D. The refractive index of material of lens is 1.5. Find the radius of curvature of each surface.**

**Sol.** $P=\frac{1}{f}$, $\therefore f=\frac{1}{P}=\frac{1}{5}\,\text{m}=20\,\text{cm}$

For an equiconvex lens

$$\frac{1}{f}=\frac{2(\mu-1)}{R}$$

$\therefore\ R=2(\mu-1)f=2\times0.5\times20=20\,\text{cm}$

**4. A lens placed at a distance of 20 cm from an object produces a virtual image 2/3 the size of the object. Find the position of the image, kind of lens and its focal length.**

**Sol.** Virtual image means, $I$ is positive and it is given that $I=(2/3)O$. Thus, $m=+2/3$

Further because $u=-20$ cm (given), using

$$m=\frac{f}{f+u}$$

we get, $\frac{2}{3}=\frac{f}{f+(-20)}$ or $f=-40\,\text{cm}$

The f is negative, thus the lens is a concave lens. Again using $m=v/u$

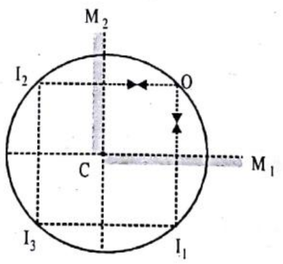
we get $\frac{2}{3}=\frac{v}{-20}$ or $v=-\frac{2}{3}=-1.33\,\text{cm}$

The virtual image is on the same side of the object.

**5. Find the number of images formed by two mutually perpendicular mirrors.**

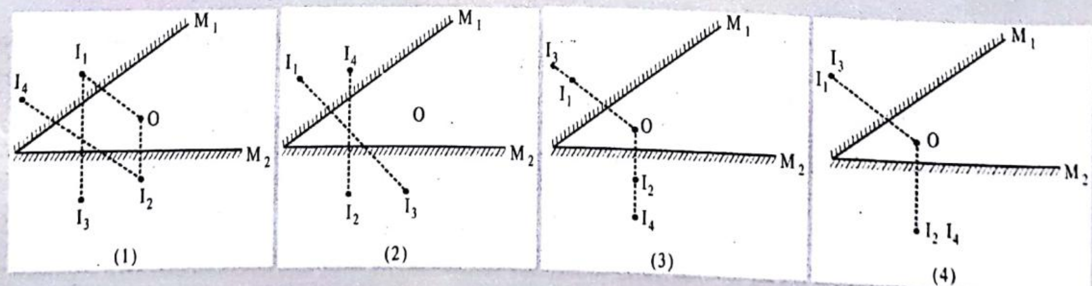
**Sol.** Here, $n=\frac{360}{\theta}=\frac{360}{90}=4$

$\therefore$ $n$ is an even number




Thus, number of images formed $=n-1=3$. All these three images lie on a circle with centre at $C$ (The point of intersection of mirrors $M_1$ and $M_2$) and whose radius is equal to the distance between $C$ and object.

**6. Two plane mirrors are inclined at an angle of 30°. Then the first four images of an object O placed between the two mirrors are correctly represented by**




**Sol.** The image of object $O$ from mirror $M_1$ is $I_2$ and the image of $I_1$ (the virtual object) from mirror $M_2$ is $I_3$. The image of object $O$ from mirror $M_2$ is $I_2$ and the image of $I_2$ (the virtual object) from mirror $M_1$ is $I_4$. Notice that this interpretation, according to ray diagram rules, is valid only for Fig. (1). All others are inconsistent. Hence correct is (1).

**7. The focal length of a concave mirror is 30 cm. Find the position of the object in front of the mirror, so that the image is three times the size of the object.**

**Sol.** Here image can be real or virtual. If the image is real

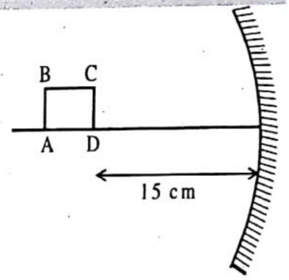
$f = -30, u = ?, m = -3$

$$m = \frac{f}{f-u} \Rightarrow -3 = \frac{-30}{-30-u} \Rightarrow u = -40 \text{ cm.}$$

If the image is virtual

$$m = \frac{f}{f-u} \Rightarrow 3 = \frac{-30}{-30-u} \Rightarrow u = -20 \text{ cm.}$$

**8. A square ABCD of side 1mm is kept at distance 15 cm infront of the concave mirror as shown in the figure. The focal length of the mirror is 10 cm. Find the length of the perimeter of its image.**



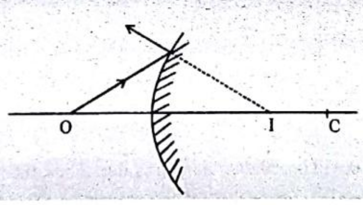

**Sol.** $v = -30,\ m = -\frac{v}{u} = -2$

$\therefore A'B' = C'D' = 2 \times 1 = 2\text{mm}$

Now $\frac{B'C'}{BC} = \frac{A'D'}{AD} = \frac{v^2}{u^2} = 4 \Rightarrow B'C' = A'D' = 4 \text{ mm}$

$\therefore$ Length $= 2 + 2 + 4 + 4 = 12$ mm

**9. A convex mirror has its radius of curvature 20 cm. Find the position of the image of object placed at a distance of 12 cm from the mirror.**




**Sol.** The situation is shown in figure.

Here $u = -12$ cm and $R = +20$ cm. We have

$$\frac{1}{u} + \frac{1}{v} = \frac{2}{R} \text{ or } \frac{1}{v} = \frac{2}{R} - \frac{1}{u}$$

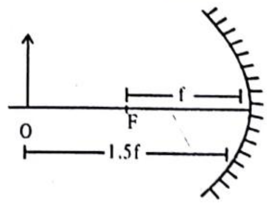
$$\Rightarrow \frac{1}{v} = \frac{2}{20}\text{ cm} - \frac{1}{-12}\text{ cm} = \frac{11}{60}\text{ cm}$$

$$v = \frac{60}{11}\text{ cm}$$

**10. An object of length 2.5 cm is placed at a distance of 1.5 *f* from a concave mirror where *f* is the magnitude of the focal length of the mirror. The length of the object is perpendicular to the principal axis. Find the length of the image. Is the image erect or inverted?**

**Sol.** The given situation is shown in figure.

The focal length $f = -f$ and $u = -1.5f$, we have




$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f} \text{ or } -\frac{1}{1.5f} + \frac{1}{v} = -\frac{1}{f}$$

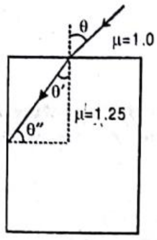
or $$\frac{1}{v} = \frac{1}{1.5f} - \frac{1}{f} = \frac{-1}{3f} \text{ or } v = -3f$$

Now $m = -\frac{v}{u} = \frac{3f}{-1.5f} = -2$ or $\frac{h_2}{h_1} = -2$

or $h_2 = -2h_1 = -5.0$ cm

The image is 5.0 cm long. The minus sign shows that it is inverted.

**11. Consider the situation shown in figure. Find maximum angle for which the light suffers total internal reflection at the vertical surface.**




**Sol.** The critical angle for this case is

$$\theta" = \sin^{-1}\frac{1}{1.25} = \sin^{-1}\frac{4}{5} \quad or \quad \sin\theta" = \frac{4}{5}$$

Since $\theta" = \frac{\pi}{2} - \theta'$, we have $\sin\theta' = \cos\theta" = \frac{3}{5}$

From Snell's law,

$$\frac{\sin\theta}{\sin\theta'} = 1.25 \quad or \quad \sin\theta = 1.25 \times \sin\theta' = 1.25 \times \frac{3}{5} = \frac{3}{4}$$

$$or \quad \theta = \sin^{-1}\frac{3}{4}$$

If θ'' is greater than the critical angle, θ will be smaller than this value. Thus, the maximum value of q' for which total internal reflection takes place at the vertical surface is $\sin^{-1}(3/4)$.

**12. A converging lens has a focal length of 20 cm in air. It is made of a material of refractive index 1.6. If the lens is immersed in a liquid of refractive index 1.3. What will be the new focal length of the lens.**

**Sol.** $\frac{1}{f_1} = (\mu_1 - 1)\frac{2}{R}$ $\qquad \mu_1 = 1.6, f_1 = 20$

$$\frac{1}{f_1} = (1.6 - 1)\frac{2}{R}$$

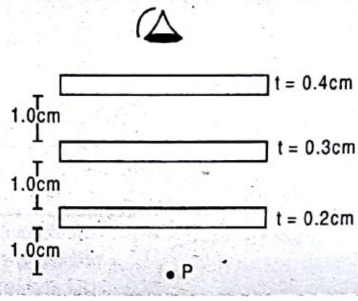
$$or \quad \frac{1}{20} = \frac{0.6 \times 2}{R} \quad \therefore R = \frac{0.6 \times 2 \times 20}{10} = 24\text{cm}$$

$$\frac{1}{f_2} = (\mu_1 - 1) \times \frac{2}{R} \quad \therefore \quad \frac{1}{f_2} = (\frac{1.6}{1.3} - 1) = \frac{2}{R}$$

$$\frac{1}{f_2} = (\frac{1.6 - 1.3}{1.3})\frac{2}{24} = \frac{0.3}{1.3} \times \frac{1}{12} = \frac{1}{52}$$

$f_2 = 52$ cm.

**13. Locate the image of the point $P$ as seen by the eye through the slabs of refrective index ($m = 1.2, 1.3, 1.4$ respectively starting from the bottom) as shown in figure.**




**Sol.** The net shift from one slab is $t\left(1-\frac{1}{\mu}\right)$ where as t is the thickness of slab, μ is the refractive index of slab. Total shift is

$$t_1\left(1-\frac{1}{\mu_1}\right)+t_2\left(1-\frac{1}{\mu_2}\right)+t_3\left(1-\frac{1}{\mu_3}\right)=0.2\left(1-\frac{1}{1.2}\right)+0.3\left(1-\frac{1}{1.3}\right)+0.4\left(1-\frac{1}{1.4}\right)$$

$$=0.2\left(\frac{0.2}{1.2}\right)+\frac{0.3\times0.3}{1.3}+\frac{0.4\times0.4}{1.4}$$

$= 0.0333 + 0.0692 + 0.114 = 0.2$ cm above $P$.

**14. A lens has a power of + 5 diopter in air. What will be its power if completely immersed in water ? Given**

$$\mu_g = \frac{3}{2};\ \mu_w = \frac{4}{3}$$

**Sol.** Let $f_a$ and $f_w$ be the focal lengths of the lens in air water respectively, then

$$P_a = \frac{1}{f_a} \quad \text{and} \quad P_w = \frac{\mu_w}{f_w}\ ;\ f_a = 0.2\,\text{m} = 20\,\text{cm}$$

Using lensmaker's formula

$$P_a = \frac{1}{f_a} = (\mu_g - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] \qquad \text{...(i)}$$

$$\frac{1}{f_w} = \left(\frac{\mu_g}{\mu_w} - 1\right)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

$$\Rightarrow P_w = \frac{\mu_w}{f_w} = (\mu_g - \mu_w)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] \qquad \text{...(ii)}$$

Dividing equation (ii) by equation (i), we get,

$$\frac{P_w}{P_a} = \frac{(\mu_g - \mu_w)}{(\mu_g - 1)} = \frac{1}{3} \quad \text{or} \quad P_w = \frac{P_a}{3} + \frac{+5}{3}D$$

# 1 EXERCISE

## Fill in the Blanks :

**DIRECTIONS :** *Complete the following statements with an appropriate word / term to be filled in the blank space(s).*

1. The power of a convex lens is ................ and that of a concave lens is .............
2. Light seems to travel in ...............
3. A light ray travelling obliquely from a denser medium to a rarer medium bends ............ the normal. A light ray bends ............. the normal when it travels obliquely from a rarer to a denser medium.
4. In case of a rectangular glass slab, the refraction takes place at both ................. interface and .............. interface. The emergent ray is .......... to the direction of incident ray.
5. Power of a lens is the reciprocal of its ................
6. The SI unit of power of a lens is ................
7. The angle of incidence is ......... to the angle of reflection.
8. The reflecting surface of a spherical mirror may be curved ............. or .............
9. The surface of the spoon can be approximated to a .......... mirror.
10. The centre of the reflecting surface of a spherical mirror is a point called the ................
11. The centre of curvature of a concave mirror lies in ......... of it.
12. Line passing through the pole and the centre of curvature of a spherical mirror is called the ................
13. A ray parallel to the principal axis, after reflection, will pass through the ....................
14. The dentists use ............... mirrors to see large images of the teeth of patients.
15. A transparent material bound by two surfaces, of which one or both surfaces are spherical, forms a ..........
16. The degree of ............ of light rays achieved by a lens is expressed in terms of its power.
17. An object is placed in front of a spherical mirror. The image is found to be virtual for all positions of the object. The spherical mirror is .........
18. Two immiscible transparent liquids A and B have 1.2 and 1.5 as their refractive indices (with respect to air). The refractive index of B with respect to A is .......

## True / False :

**DIRECTIONS :** *Read the following statements and write your answer as true or false.*

1. The reflecting surfaces, of all types, obey the laws of reflection.
2. The magnification produced by a spherical mirror is the ratio of the height of the image to the height of the object.
3. Light travels in vacuum with an enormous speed of $3 \times 10^8\ ms^{-1}$.
4. The speed of light is different in different media.
5. The refractive index of a transparent medium is the ratio of the speed of light in vacuum to that in the medium.
6. The incident ray, the normal to the mirror at the point of incidence and the reflected ray, all lie in the same plane.
7. Centre of curvature is not a part of the mirror.
8. Image formed by a plane mirror is always virtual and erect.
9. The principal focus of a spherical mirror lies midway between the pole and centre of curvature.
10. Convex mirrors enable the driver to view much larger area than would be possible with a plane mirror.
11. A concave lens will always give a virtual, erect and diminished image.
12. A ray of light passing through the optical centre of a lens will emerge without any deviation.
13. A plane mirror can form virtual images.
14. An object is placed in front of a mirror and an image of it is formed at the object itself. The mirror mentioned in question is a convex mirror.
15. A concave mirror can produce both real and virtual images.
16. Light travels faster in glass than in air.

## Match the Following :

**DIRECTIONS :** *Each question contains statements given in two columns which have to be matched. Statements (A, B, C, D) in column I have to be matched with statements (p, q, r, s) in column II.*

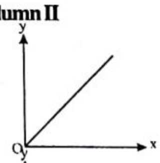
1. Match the following :

| Column I | Column II |
|---|---|
| (A) Power of convex mirror | (p) Positive power |
| (B) Power of concave mirror | (q) Negative power |
| (C) Power of plane mirror | (r) Zero power |
| (D) Power of convex lens | (s) Infinite power |

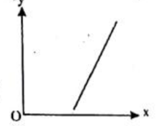
2. The graphs given apply to convex lens of focal length $f$, producing a real image at a distance $v$ from the optical centre when self luminous object is at distance $u$ from the optical centre. The magnitude of magnification is $m$. Identify the following graphs with the first named quantity being plotted along y-axis.

**Column I** | **Column II**

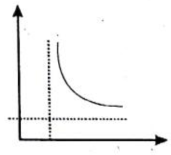
(A) $v$ against $u$ (p)



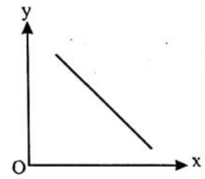

(B) $\frac{1}{v}$ against $\frac{1}{u}$ (q)




(C) $m$ against $v$ (r)



(D) $(m+1)$ against $\frac{v}{f}$ (s)




## Very Short Answer Questions :

**DIRECTIONS :** *Give answer in one word or one sentence.*

1. If you want to see an enlarged image of your face, state whether you will use a concave mirror or a convex mirror?
2. In case of a spherical mirror, do both the sides act as reflecting surfaces?
3. For driving a car, what type of mirror would you prefer to see the traffic at your back?
4. A ray of light passes through the optical centre of a lens. Does it suffer any deviation?
5. Will the focal length of the lens change when it is put in water?
6. Define the principal focus of a concave mirror.
7. What is a ray?
8. What is the radius of a plane mirror?
9. Why does a convex mirror has a virtual principal focus ?
10. What is the nature of light?
11. What is spherical mirror?
12. For what position of an object, a concave mirror forms a virtual and magnified image?
13. What type of mirror is formed when a mercury drop falls on the earth?
14. Define refraction.
15. What is a rarer medium?
16. What is a lens?
17. Define one dioptre.
18. Write down the magnification formula for a lens in terms of object distance and image distance. How does it differ from the corresponding formula for a mirror?
19. Differentiate between virtual image of a concave mirror and of a convex mirror.
20. How does the frequency of a beam of ultra violet light change when it goes from air into glass?
21. When light undergoes refraction at the surface of separation of two media, what happens to its wavelength?
22. How does a focal length of convex lens change if monochromatic red light is used instead of monochromatic blue light?

## Short Answer Questions :

**DIRECTIONS :** *Give answer in two to three sentences.*

1. A person is in a room whose ceiling and two adjacent walls are mirrors. (a) How many images are formed? (b) How many images of himself can he see ? (c) Are all the images virtual and erect ?
2. A high flying bird does not cast shadow on the ground. Why?
3. What is the difference between the images formed by a large and a small mirror?
4. For a plane mirror what is the focal length and the magnification?
5. The level of clear water in a clear colourless glass can be seen easily, but that of liquid helium cannot be. Why?
6. Why is convex mirror preferred as rear-view mirror in cars?
7. What do you mean by a normal to the reflecting surface?
8. What do you mean by a focal plane ?
9. A concave mirror produces three times magnified (enlarged) real image of an object placed at 10 cm in front of it. Where is the image located?
10. Light enters from air to glass having refractive index 1.50. What is the speed of light in the glass? The speed of light in vacuum is $3 \times 10^8$ ms$^{-1}$.
11. The refractive index of diamond is 2.42. What is the meaning of this statement.
12. Find the power of a concave lens of focal length 2 m.
13. Find the focal length of a lens of power –2.0 D. What type of lens is this ?
14. In what way is the word AMBULANCE printed infront of the hospital vans? Why is it printed this way?
15. A convex lens is of focal length 10 cm what is its power?
16. You read a newspaper because of the light that it reflects. Then why do you not see even a faint image of yourself in the newspaper?
17. The wall of a room is covered with a perfect plane mirror. Two movie films are made, one recording the movement of a man and the other of his image. From viewing the films later, can an outsider tell which is which?
18. Under what condition will a concave mirror produce an erect image? A virtual image ? An image smaller than the object? An image larger than the object?

19. The image of an object formed by a lens on the screen is not in sharp focus. Suggest a method to get clear focussing of the image on the screen without disturbing the position of the object, the lens or the screen.
20. Refractive index of glass for light of yellow, green and red colours are $\mu_y$, $\mu_g$ and $\mu_r$ respectively. Rearrange these symbols in the increasing order of values.
21. Give the ratio of velocities of light rays of wavelengths 4000 Å and 8000 Å.
22. An object is placed at a distance of 12 cm in front of a concave mirror. It forms a real image four times larger than the object. Calculate the distance of the image from the mirror.
23. With respect to air, the refractive index of ice is 1.31 arid that of rock salt is 1.54. Calculate the refractive index of rock salt with respect to ice.
24. Light enters from air into glass plate which has a refractive index of 1.50. Calculate the speed of light in glass. The speed of light in air is $3 \times 10^8$ ms$^{-1}$.
25. A concave mirror and a convex lens are held separately in water. What changes, if any, do you expect in the focal length of either?

## LAQ Long Answer Questions

**DIRECTIONS :** *Give answer in four to five sentences.*

1. Prove the mirror formula for reflection of light from a concave mirror.
2. An object 5.0 cm in length is placed at a distance of 20 cm. in front of a convex mirror of radius of curvature 30 cm. Find the position of the image, its nature and size.
3. A truck uses a convex mirror as view finder whose radius of curvature is 2.0 m. A maruti car is coming behind the truck at a distance of 10 m. What will be the position of the image of the car and size of the image of the car when observed by the driver of the truck through the convex mirror?
4. An object is placed 90 cm away from a concave mirror of focal length 30 cm. Find the position and the nature of the image formed.
5. Two thin converging lenses of focal lengths 0.15 m and 0.30 m are held in contact with each other. Calculate power and focal length of combination.
6. What is the focal length of a convex lens of focal length 30 cm. in contact with a concave lens of focal length 20 cm? Is the system a converging or diverging lens? Ignore thickness of the lenses.
7. Two thin lenses of focal lengths + 10 cm and – 5cm are kept in contact. What is the focal length and power of the combination?
8. If the wavelength of incident light on a (i) concave mirror and (ii) convex lens is increased, how will the focal length of each of these change?
9. Use the mirror formula to show that for an object lying between the pole and focus of a concave mirror, the image formed is always virtual in nature.
10. A concave lens has focal length of 20 cm. At what distance from the lens a 5 cm tall object be placed so that it forms an image at 15 cm from the lens? Also calculate the size of the image formed.

# 2 EXERCISE

## MCQ Multiple Choice Questions

**DIRECTIONS :** *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONLY ONE is correct.*

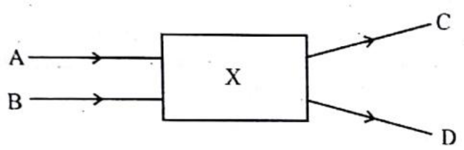
1. Where should an object be placed in front of a convex lens to get a real image of the size of the object?
   (a) At the principal focus of the lens
   (b) At twice the focal length
   (c) At infinity
   (d) Between the optical centre of the lens and its principal focus.
2. A spherical mirror and a thin spherical lens have each a focal length of –15 cm. The mirror and the lens are likely to be
   (a) both concave.
   (b) both convex.
   (c) the mirror is concave and the lens is convex.
   (d) the mirror is convex, but the lens is concave.
3. Which of the following lenses would you prefer to use while reading small letters found in a dictionary?
   (a) A convex lens of focal length 50 cm.
   (b) A concave lens of focal length 50 cm.
   (c) A convex lens of focal length 5 cm.
   (d) A concave lens of focal length 5 cm.
4. One light wave is incident upon a plate of refracting index $\mu$. Incident angle $i$, for which refractive & reflective waves are mutually perpendicular will be
   (a) $i = 45°$ (b) $i = \sin^{-1}(\mu)$
   (c) $i = \operatorname{cosec}^{-1}(\mu)$ (d) $i = \tan^{-1}(\mu)$
5. An object is situated at a distance of $f/2$ from a convex lens of focal length $f$. Distance of image will be –
   (a) $+(f/2)$ (b) $+(f/3)$
   (c) $+(f/4)$ (d) $-f$
6. An object is placed 60 cm in front of a concave mirror. The real image formed by the mirror is located 30 cm in front of the mirror. What is the object's magnification?
   (a) +2 (b) –2
   (c) +0.5 (d) –0.5

7. Two plane mirrors are set at right angle and a flower is placed in between the mirrors. The number of images of the flower which will be seen is
(a) One (b) Two
(c) Three (d) Four

8. A man is 6.0 ft tall. What is the smallest size plane mirror he can use to see his entire image
(a) 3.0 ft (b) 6.0 ft
(c) 12 ft (d) 24 ft

9. An object is placed 60 cm in front of a convex mirror. The virtual image formed by the mirror is located 30 cm behind the mirror. What is the object's magnification
(a) +2 (b) −2
(c) +0.5 (d) −0.5

10. Light rays $A$ and $B$ fall on optical component $X$ and come out as $C$ and $D$.




The optical component is a
(a) concave lens (b) convex lens
(c) convex mirror (d) prism

11. An object is placed 20.0 cm in front of a concave mirror whose focal length is 25.0 cm. What is the magnification of the object?
(a) +5.0 (b) −5.0
(c) +0.20 (d) −0.20

12. An object is placed at the radius of curvature of a concave spherical mirror. The image formed by the mirror is
(a) located at the focal point of the mirror.
(b) located between the focal point and the radius of curvature of the mirror.
(c) located at the center of curvature of the mirror.
(d) located out beyond the center of curvature of the mirror.

13. If the refractive indices for water and diamond relative to air are 1.33 and 2.4 respectively, then the refractive index of diamond relative to water is –
(a) .55 (b) 1.80
(c) 3.19 (d) None of these

14. There is an equiconvex lens of focal length of 20cm. If the lens is cut into two equal parts perpendicular to the principle axis, the focal lengths of each part will be
(a) 20 cm (b) 10 cm
(c) 40 cm (d) 15 cm

15. An object is placed 20.0 cm in front of a concave mirror whose focal length is 25.0 cm. Where is the image located?
(a) $1.0 \times 10^2$ cm in front of the mirror
(b) $1.0 \times 10^2$ cm behind the mirror
(c) $5.0 \times 10^1$ cm in front of the mirror
(d) $5.0 \times 10^1$ cm behind the mirror

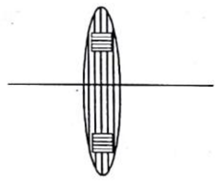
16. When viewed vertically a fish appears to be 4 meter below the surface of the lake. If the index of refraction of water is 1.33, then the true depth of the fish is
(a) 5.32 metres (b) 3.32 metres
(c) 4.32 metres (d) 6.32 metres

17. Light waves
(a) Require air or another gas to travel through
(b) Require an electric field to travel through
(c) Require a magnetic field to travel through
(d) Can travel through perfect vacuum

18. An object is placed 40.0 cm in front of a convex mirror. The image appears 15 cm behind the mirror. What is the focal length of the mirror?
(a) +24 cm (b) +11 cm
(c) −11 cm (d) −24 cm

19. Morning sun is not so hot as the mid day sun because
(a) Sun is cooler in the morning
(b) Heat rays travel slowly is the morning
(c) It is God gift
(d) The sun's rays travel a longer distance through atmosphere in the morning

20. The layered lens shown below is made of two different transparent materials.



A point object is placed on its axis. The object will form
(a) one image (b) infinite images
(c) no image (d) two images

21. An object is placed in front of a concave mirror of focal length 50.0 cm and a real image is formed 75 cm in front of the mirror. How far is the object from the mirror
(a) 25 cm (b) 30 cm
(c) 150 cm (d) −150 cm

22. A number of images of a candle flame can be seen in a thick mirror. The brightest image is
(a) Fourth (b) Second
(c) Last (d) First

23. A ray from air enters water, then through a thick layer of glass placed below water. After passing through glass, it again comes out in air medium. Then final emergent ray will
(a) Bend towards the normal
(b) Bend away from the normal
(c) Suffer lateral displacement
(d) Have the same path as if it had not passed through glass and water.

24. A concave spherical mirror has a radius of curvature of 100 cm. What is its focal length
(a) 50 cm (b) 100 cm
(c) 200 cm (d) 300 cm

25. Light is incident on an air-water interface at an angle of 25° to the normal. What angle does the refracted ray make with the normal
(a) 19° (b) 34°
(c) 25° (d) 90°

26. Light reflected from a boundary between an unknown substance and air is seen to become 100% polarized when the angle of incidence is 62.0°. What is the index of refraction of the unknown substance?
(a) 1.88 (b) 1.13
(c) 2.14 (d) 0.532

27. An object is placed 10.0 cm from a diverging lens which forms an image 6.5 cm from the lens. What is the focal length of the lens? Include the sign.
(a) +3.9 cm (b) −16.5 cm
(c) −21.2 cm (d) −18.6 cm

28. Under what conditions does a diverging lens form a virtual image of a real object
(a) Only if $u > f$.
(b) Only if $u < f$.
(c) Only if $u = f$
(d) A diverging lens always forms a virtual image of a real object.

29. A convex lens of focal length 25 cm receives light from the sun. A diverging lens of focal length – 12 cm is placed 37 cm to the right of the converging lens. Where is the final image located relative to the diverging lens?
(a) 6 cm to the left (b) 25 cm to the left
(c) At infinity (d) 12 cm to the right

30. A lens produces a enlarged, virtual image. What kind of lens is it?
(a) converging
(b) diverging
(c) It could be either diverging or converging.
(d) None

31. A camera lens focuses light from a 12.0 m tall building located 35.0 m away on film 50.0 mm behind the lens. How tall is the image of the building on the film?
(a) 17.1 mm (b) 7.00 mm
(c) 2.50 cm (d) 1.25 mm

32. In an experiment to determine the focal length of a concave lens, a student obtained the image of a distant window on the screen. To determine the focal length of the lens, she/he should measure the distance between the
(a) lens and the screen only
(b) lens and the window only
(c) screen and the window only
(d) screen and the lens and also between the screen and the window

33. On the basis of experiment 'to trace the path of a ray of light passing through a rectangular glass slab' four students arrived at the following interpretations :
I. Angle of incidence is greater than the angle of emergence.
II. Angle of emergence is less than the angle of refraction.
III. Emergent ray is parallel to the incident ray.
IV. Emergent ray is parallel to the refracted ray.
The correct interpretation is that of the student.
(a) I (b) II
(c) III (d) IV

34. Light waves
(a) are mechanical waves
(b) are electromagnetic waves
(c) travel with the same velocity in all media
(d) requires a material medium for their propagation

35. Virtual images of object of the same size are formed by
(a) a concave mirror (b) a convex mirror
(c) a plane mirror (d) all the above

36. Two plane inclined mirrors form 5 images by multiple reflection. The angle of inclination is
(a) 90° (b) 60°
(c) 45° (d) 30°

37. A bright × (cross) mark is made on a sheet of white paper. Over the white paper a rectangular glass-slab of thickness 3 cm is placed. On looking through, the image of the mark appears above the mark. It is below the upper surface of the slab by
(a) 2.5 cm (b) 1.5 cm
(c) 2 cm (d) 1.75 cm

38. The critical angle of a transparent medium denser than air
(a) increases with its refractive index
(b) decreases with its refractive index
(c) is independent of its refractive index
(d) None of these

39. Orange, blue and yellow are 3 of the colours formed by a prism. Their order according to increasing deviation is
(a) blue, orange, yellow (b) yellow, blue, orange
(c) blue, yellow, orange (d) orange, yellow, blue

40. Images formed by an object placed between two plane mirrors whose reflecting surfaces make an angle of 90° with one another lie on a
(a) Straight line (b) Zig-zag curve
(c) Circle (d) Ellipse

41. A diver in a swimming pool wants to signal his distress to a person lying on the edge of the pool by flashing his waterproof torch
(a) He must direct the beam of light vertically upwards
(b) He must direct the beam horizontally
(c) He must direct the beam at an angle to the vertical which is slightly lesser than the critical angle
(d) He must direct the beam at an angle to the vertical which is slightly greater than the critical angle

**42.** Two plane mirrors are inclined at an angle $\theta$. A ray of light is incident on one mirror and is then reflected from the other mirror. Then the angle between the first ray and the final ray will be

(a) $\theta$ (b) $2\theta$
(c) between $\theta$ and $2\theta$ (d) $>2\theta$

**43.** In comparison to the case when a ray of light travels from glass to air, the critical angle for total internal reflection of light when a ray of light travels from glass to water is

(a) greater (b) smaller
(c) same (d) nothing can be predicted

**44.** A glass slab is placed in the path of a beam of convergent light, then the point of convergence of light

(a) moves towards the glass slab
(b) moves away from the glass slab
(c) remains at the same point
(d) undergoes a lateral shift

**45.** A real image is formed by a convex mirror when the object is placed at

(a) infinite
(b) between center of curvature and focus
(c) between focus and pole
(d) none of the above

**46.** A virtual image is formed by a concave mirror when the object is placed between

(a) infinity and center of curvature
(b) center of curvature and focus
(c) focus and the pole
(d) All of the above

**47.** Which of the following are used in a Kaleidoscope

(a) plane mirrors (b) concave
(c) convex mirrors (d) all of the above

**48.** When a spherical convex lens made up of glass is immersed in water, its focal length

(a) decreases (b) does not change
(c) increases (d) none of the above

**49.** Out of the following

(a) pole (b) focus
(c) radius of curvature (d) principal axis

for a spherical mirror, the quantities that do not depend on whether the rays are paraxial or not, are

(a) a, b, c and d (b) only a, b and c
(c) only a, c and d (d) only a and d

**50.** A person standing at some distance from a mirror finds his image erect, virtual and of the same size. Then the mirror is possibly

(a) plane mirror
(b) concave mirror
(c) plane or concave mirror
(d) plane or concave or convex mirror

## MTOC More than One Correct :

**DIRECTIONS :** *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONE OR MORE may be correct.*

**1.** Which of the following materials be used to make a lens?

(a) Water (b) Glass
(c) Plastic (d) Clay

**2.** The image formed by a concave mirror is observed to be virtual, erect and larger than the object. Where should not be the position of the object?

(a) Between the principal focus and the centre of curvature
(b) At the centre of curvature
(c) Beyond the centre of curvature
(d) Between the pole of the mirror and its principal focus.

**3.** No matter how far you stand from a mirror, your image appears erect. The mirror may be

(a) plane (b) concave
(c) convex (d) none of these

**4.** A lens behaves as a converging lens in air and diverging lens in water. The refractive index of the material of the lens can't be

(a) 1 (b) between 1 and 1.33
(c) 1.33 (d) greater than 1.33

**5.** On passing through a glass slab, red light doesn't suffer a change of

(a) wavelength (b) frequency
(c) amplitude (d) velocity

**6.** The focal length of a concave mirror doesn't depend upon

(a) The radius of curvature of the mirror
(b) The object distance from the mirror
(c) The image distance from the mirror
(d) The material of mirror

**7.** The radius of curvature of a plane mirror can't be

(a) zero (b) infinite
(c) negative (d) finite

**8.** Tick out the correct statements in the following

(a) Light travels with a speed greater than that of sound
(b) Light cannot travel through vacuum
(c) Light travels in a straight line
(d) Light has no weight

**9.** Choose the wrong statements regarding the image formation in a convex spherical mirror

(a) Images are always larger than the actual object
(b) Images are always smaller than the actual object
(c) Images are always of the same size as the actual object
(d) Images are always half of the actual object

**10.** The image formed by a convex spherical mirror is

(a) virtual (b) erect
(c) real (d) inverted

11. When light passes from air into glass it experiences a change of
(a) Speed (b) Wavelength and speed
(c) Frequency (d) amplitude

12. If a real object is placed inside the focal point of a concave mirror, the image is
(a) upright (b) real
(c) virtual (d) inverted

13. A person standing infront of a mirror finds his image smaller than himself and erect. This implies the mirror must not be
(a) plane (b) concave
(c) convex (d) None of the above

14. Choose the wrong statements regarding refraction of light
(a) The bending of light rays when they enter from one medium to another medium
(b) Splitting of white light into seven colours when it passes through the prism
(c) Bending of light round corners of obstacles and apertures
(d) Coming back of light from a bright smooth surface

15. A converging lens has a focal length of 15 cm. An object is placed 9.0 cm from the lens. Describe the image formed
(a) upright (b) inverted
(c) virtual (d) enlarged

16. Four students reported the following observation tables for the experiment, to trace the path of a ray of light passing through a glass slab for different angles of incidence. The observations, likely to be wrong are those of student.

I

| i | r | e |
|---|---|---|
| 30° | 40° | 30° |
| 40° | 50° | 40° |
| 50° | 50° | 50° |

II

| i | r | e |
|---|---|---|
| 30° | 20° | 30° |
| 40° | 30° | 40° |
| 50° | 40° | 50° |

III

| i | r | e |
|---|---|---|
| 30° | 20° | 40° |
| 40° | 30° | 50° |
| 50° | 40° | 60° |

IV

| i | r | e |
|---|---|---|
| 30° | 20° | 20° |
| 40° | 30° | 30° |
| 50° | 40° | 40° |

(a) I (b) II
(c) III (d) IV

17. The absolute refractive index of a medium depends on
(a) nature of the medium only
(b) wavelength of light only
(c) temperature of the medium only
(d) the angle of incidence

18. Mark the correct statements
(a) Refractive index decreases with increase in temperature
(b) Refractive index depends on the angle of incidence
(c) Foucault demonstrated experimentally that the speed of light in air is more than that in water
(d) Polarization of light was discovered by Malus

19. Mark the correct statements about a virtual image
(a) A virtual image can be photographed
(b) A virtual image can be seen
(c) A virtual image can be photographed by exposing a film at the location of the image
(d) A virtual image may be diminished or enlarged in size in comparison to an object.

20. Mark the correct statements
(a) A convex mirror produces an erect image
(b) A convex mirror always produces an erect image of an erect object
(c) A convex mirror always produces a diminished in size image
(d) A convex mirror is used as a shaving mirror

21. In vacuum the speed of light does not depend on
(a) Wavelength (b) Frequency
(c) Intensity (d) Speed of observer

22. When light passes from air to water which of the following changes
(a) Wavelength (b) Velocity
(c) Frequency (d) Colour

23. In case of reflection by a plane-mirror, which of the following statements are not correct
(a) It can never give real image
(b) It can never give inverted image
(c) It changes left into right
(d) It changes front into back

24. If two mirrors are inclined to each other at 90°, the image seen may be
(a) One (b) Two
(c) Three (d) Four

25. In case of three plane-mirrors meeting at a point to form a corner of a cube, if incident light suffers one reflection on each mirror
(a) The emergent ray is antiparallel to incident one
(b) The emergent ray is perpendicular to incident one
(c) The emergent ray is in phase with incident one
(d) The emergent ray is in opposite phase with incident one

26. A plane mirror, reflecting a ray of incident light, is rotated through an angle $\theta$ about an axis through the point of incidence in the plane of the mirror perpendicular to the plane of incidence, then
(a) the reflected ray does not rotate
(b) the reflected ray rotates an angle $\theta$
(c) the reflected ray rotates an angle $2\theta$
(d) the incident ray is fixed

27. Five images are formed, if two plane-mirrors are inclined to each other at an angle of
(a) 60° (b) 70°
(c) 72° (d) 90°

**28.** Out of the following which statements are correct?

(a) Two plane mirrors are inclined to each other at an angle of 60°. If a ray of light incident on the first mirror is parallel to the second mirror, it is reflected from the second mirror parallel to the first mirror.

(b) A bird flying high up in the air does not cast a shadow on the ground because layers of atmosphere are dense.

(c) If a ray reflected successively from two plane mirrors inclined at a certain angle undergoes a deviation of 300°, then the number of images observable is 11.

(d) A clock indicates a time of 3.25. On seeing it in a plane mirror, the time appears as 8.35.

## FIP Fill in the Passage :

**DIRECTIONS :** *Fill in the blanks in the following passage(s) from the words given inside the box.*

**I.**

| | | |
|---|---|---|
| reflected | greater than | 90° |
| away | critical angle | total internal reflection |

When a ray of light passes from denser to rarer medium, the refracted ray bends ..........1.......... from the normal. Hence the angle of refraction is ..........2.......... the angle of incidence. Gradually if the angle of incidence increases, angle of refraction also increases. At a particular angle of incidence, the refracted ray just grazes the refracting surface or the angle of refraction is equal to ..........3.......... . This angle of incidence in the denser medium is called ..........4.......... . If the angle of incidence is further increased the rays do not undergo refraction, it gets ..........5.......... into the same optically denser medium. This is known as ..........6.......... .

**II.**

| | | |
|---|---|---|
| convex lens | thinner | two |
| concave lens | one | thicker |

A lens is a transparent material which is bounded by ..........1.......... spherical surfaces or one spherical surface and one plane surface. Lens are of two types, namely ..........2.......... and ..........3.......... . A convex lens has one or two spherical surfaces, such that it is ..........4.......... at the centre than at the edges. A concave lens has one or two spherical surfaces, such that it is ..........5.......... at the centre than at its edge.

**III.**

| | | |
|---|---|---|
| concave lens | focal length | |
| negative | positive | optical centre |

Cartesian sign convention is used now-a-days. According to this convention, all distances are measured from ..........1.......... . Distances measured in the direction of incident light is taken as ..........2.......... and distance measured against incident light is taken as ..........3.......... . According to sign convention, ..........4.......... of a couvex lens is positive and that of the ..........5.......... is negative.

## PBQ Passage Based Questions :

**DIRECTIONS :** *Study the given passage(s) and answer the following questions.*

**Passage-I**

Inside a substance such as glass or water, light travels more slowly than it does in a vacuum. If $c$ denotes the speed of light in a vacuum and $v$ denotes its speed through some other substance, then $v = c/n$

where $n$ is a constant called the index of refraction.

To good approximation, a substance's index of refraction does not depend on the wavelength of light. For instance, when red and blue light waves enter water, they both slow down by about the same amount. More precise measurements, however, reveal that $n$ varies with wavelength. Table presents some indices of refraction of Custon glass, for different wavelengths of visible light. A nanometer (nm) is $10^{-9}$ meters. In a vacuum, light travels as $c = 3.0 \times 10^8$ m/s

**Table : Indices of refraction of Custon glass**

| Approximately colour | Wavelength in vacuum (nm) | Indices n |
|---|---|---|
| yellow | 580 | 1.5 |
| yellow orange | 600 | 1.498 |
| orange | 620 | 1.496 |
| orange red | 640 | 1.494 |

**1.** Inside Custon glass

(a) Orange light travels faster than yellow light

(b) Yellow light travels faster than orange light

(c) Orange and Yellow light travels equally fast

(d) We cannot determine which color of light travels faster

**2.** For blue-green of wavelength 520 nm, the index of refraction of Custon glass is probably closest to

(a) 1.49 (b) 1.50

(c) 1.51 (d) 1.52

**3.** Which of the following phenomena happens because n varies with wavelength

(a) A lens focuses light

(b) A prism breaks sunlight into different colors

(c) Total internal reflections ensures that light travels down a fiber optic cable

(d) Light rays entering a pond change direction at the pond's surface

**Passage-II**

A convex lens of focal length 20 cm is placed in contact with a concave lens of focal length 60 cm.

**1.** The power of the convex lens is

(a) +5 D (b) −5D

(c) +1.67 D (d) −1.67 D

2. The power of the concave lens is
   (a) +5D (b) −5D
   (c) −1.67 D (d) +1.67 D
3. The focal length of the combination of lenses is
   (a) +20 cm (b) +30 cm
   (c) −20 cm (d) −30 cm

**Passage-III**

A 5.0 cm tall object is placed perpendicular to the principal axis of a convex lens of focal length 20 cm. The distance of the object from the lens is 30 cm.

1. What is the distance of image from the pole of lens?
   (a) $v = 60$ cm (b) $v = -60$ cm
   (c) $v = 30$ cm (d) $v = -30$ cm
2. The size of the image formed by the lens is
   (a) 1 twice the object size
   (b) halved the object size
   (c) one-fourth the object size
   (d) one -third the object size
3. What is the power of the used lens?
   (a) +5 D (b) −5 D
   (c) +0.5 D (d) −0.5 D

## A&R Assertion & Reason :

**DIRECTIONS :** *Each of these questions contains an Assertion followed by Reason. Read them carefully and answer the question on the basis of following options. You have to select the one that best describes the two statements.*

(a) If both **Assertion** and **Reason** are **correct** and Reason is the **correct explanation** of Assertion.

(b) If both **Assertion** and **Reason** are correct, but Reason is **not the correct explanation** of Assertion.

(c) If **Assertion** is **correct** but **Reason** is **incorrect.**

(d) If **Assertion** is **incorrect** but **Reason** is **correct.**

1. **Assertion :** A point object is placed at a distance of 26 cm from a convex mirror of focal length 26 cm. The image will not form at infinity.

   **Reason :** For above given system the equation $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$ gives $v = \infty$.

2. **Assertion :** When a concave mirror is held under water, its focal length will increase.

   **Reason :** The focal length of a concave mirror is independent of the medium in which it is placed.

3. **Assertion :** A convex mirror is used as a driver's mirror.

   **Reason :** Because convex mirror's field of view is large and images formed are virtual, erect and diminshed.

4. **Assertion :** In visible light $\mu_r < \mu_v$

   **Reason:** This follows from Cauchy's formula

   $$\mu = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4}$$

5. **Assertion :** Keeping a point object fixed, if a plane mirror is moved, the image will also move.

   **Reason :** In case of a plane mirror, distance of object and Its image is equal from any point on the mirror.

6. **Assertion :** When the object moves with a velocity $\bar{v}$, its image in the plane mirror moves with a velocity of $-2\bar{v}$.

   **Reason :** The minimum height of the mirror to be required to see the full image of man of height $h$ is $\frac{h}{2}$.

7. **Assertion :** If both plane mirror and object are moved through a distance $x$, then the image moves through a distance $2x$.

   **Reason :** When the object is fixed and plane mirror is moved through a distance $x$. Then the image is also moves through the distance $2x$.

8. **Assertion :** As the temperature of a medium increases the refractive index decreases.

   **Reason :** When a ray travels from vacuum to a medium, then μ is known as absolute refractive index of the medium. ($\mu_{vacuum} = 1$).

9. **Assertion :** If a spherical mirror is dipped in water, its focal length remains unchanged.

   **Reason :** A laser light is focused by a converging lens. There will be a significant chromatic aberration.

10. **Assertion :** A virtual image cannot be photographed.

    **Reason :** Only real objects are photographed.

11. **Assertion :** The small object, to be seen in a microscope, is kept within the two foci of its objective.

    **Reason :** In this case, the image formed by the objective is nearer to the eyepiece.

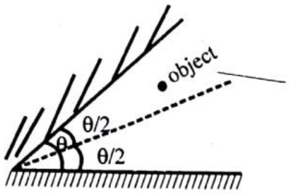
12. **Assertion :** A point source of light is placed at a distance of 2f from a converging lens of focal length $f$. The intensity of the other side of the lens is maximum at distance $2f$.

    **Reason :** In chromatic aberration the rays of different colours fail to converge at a point after going through a converging lens.

13. **Assertion :** Light rays retrace their path when their direction is reversed (Law of reversibility of light rays)

    **Reason :** For the refraction light, water is denser than air, but for the refraction of sound, water is rarer than air.

14. **Assertion :** If the angle between the two plane mirror is 72° and the object is asymmetrically placed between the two mirrors, then 5 images of the object will be formed.




**Reason :** For given system of mirror the total number of images formed due to successive reflection is equal to either $\frac{360°}{\theta}$ or $\frac{360°}{\theta} - 1$ accordingly as $\frac{360°}{\theta}$ is odd or even respectively.

**15.** **Assertion :** Red light travels faster in glass than green light.
**Reason :** The refractive index of glass is less for red light than for green light.

**16.** **Assertion :** Speed of light in glass of $\mu = 1.5$ is $2 \times 10^8$ m/sec
**Reason :** According to dual theory, light has particle nature and wave nature simultaneously.

**17.** **Assertion :** As light travels from one medium to another, the frequency of light does not change.
**Reason :** Because frequency is the characteristic of source.

## MMQ Multiple Matching Questions :

**DIRECTIONS :** *Each question has four statements (A, B, C and D) given in Column I and five statements (p, q, r, s and t) in Column II. Any given statement in Column I can have correct matching with one or more statement(s) given in Column II. Match the entries in column I with entries in column II.*

**1.** A convex lens ($f$) forms an image on a screen Considering the object to be at the zero mark in a scale, match the following.

| Column I | Column II |
|---|---|
| (A) Image | (p) Moves the image of infinite object further away |
| (B) Additional lens in contact | (q) Not unique as lens is moved between object and source. |
| (C) Reduction in refractive index | (r) Virtual for screen position at a distance $< 4f$ from the object. |
| (D) Slicing the lens to have one plane and another | (s) Object at $d$ forms real image further convex surface nearer plano-convex lens. |

**2.** In the followoing columns, the positon of an object is given is column I and the nature of image formed in aconcave mirror is given isn column II.

| Column I (Position of object) | Column II (Nature of image) |
|---|---|
| (A) At infinity | (p) Real |
| (B) Between infinity and centre of curvature | (q) Inverted |
| (C) At centre of curvature | (r) Diminished |
| (D) At focus | (s) Enlarged |
| | (t) Same size |

## HOTS Subjective Questions :

**DIRECTIONS :** *Answer the following questions.*

**1.** A truck uses a convex mirror as view finder whose radius of curvature is 2.0 m. A maruti car is coming behind the truck at a distance of 10m. What will be the position of the image of the car and size of the image of the car when observed by the driver of the truck through the convex mirror?

**2.** An object is placed at a distance of 15 cm from a convex mirror of focal length 30 cm. Find the position and the nature of the image.

**3.** A monochromatic ray of light strikes the surface of a transparent medium at an angle of incidence 60° and gets refracted into the medium at an angle of refraction 45°. What is the refractive index of the medium?
$[\sin 60° = 0.866, \sin 45° = 0.707]$

**4.** An object 3 cm in height is placed 20cm from convex lens of focal length 12 cm. Find the nature, position and height of the image.

**5.** A real image, 4/5 size of the object is formed 18 cm from a lens. Calculate the focal length of the lens.

**6.** A concave lens has focal length of 15 cm. At what distance should the object from the lens be placed so that it forms an image at 10 cm from the lens ? Also, find the magnification produced by the lens.

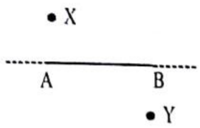
**7.** A man standing in front of a spherical mirror, finds his image having a very small head, a fat body and legs of normal size. What types of mirrors are used in the small parts?

**8.** A glass block 3.0 m thick is placed over a stamp. Calculate the height through which image of stamp is raised. Refractive index of glass is 1.54.

**9.** A postage stamp placed under a glass, appears raised by 8 mm. If refractive index of glass is 1.5, calculate the actual thickness of glass slab.

**10.** A 5 cm tall object is placed on the principal axis of diverging lens of focal length 15 cm and at a distance of 10 cm from it. Find the nature, position and size of image.

11. An image Y is formed of a point object X by a lens whose optic axis is AB as shown in figure. Draw a ray diagram to locate the lens and its focus. If the image Y of the object X is formed by a concave mirror (having the same optic axis AB) instead of lens, draw another ray diagram to locate the mirror and its focus. Write down the steps of construction of the ray diagrams.




12. A concave spherical mirror has a radius of curvature of 40 cm. Draw ray diagrams to locate the image (if one is formed) for an object at a distance of (a) 100 cm, (b) 40cm, (c) 20 cm and (d) 10 cm from the mirror. For each case, state whether the image is real or virtual, erect or inverted, and enlarged, reduced, or the same size as the object.
13. In previous question instead of concave if convex mirror (same radius of curvature) is used what will be the answer.
14. A beam of light converges to a point P. A lens is placed in the path of the convergent beam 12 cm from P. At what point does the beam converge if the lens is (a) a convex lens of focal length 20 cm, and
(b) a concave lens of focal length 16 cm?
15. **(a)** Determine the 'effective focal length' of the combination of a convex lens of focal length 30 cm and a concave lens of focal length 20 cm. If they are placed 8 cm apart with their principal axes coincident. Does the answer depend on which side a beam of parallel light is incident? Is the notion of the effective focal length of this system useful at all?
**(b)** An object 1.5 cm in size is placed on the side of the convex lens in the above arrangement. The distance between the object and the convex lens is 40 cm. Determine the magnification produced by the two-lens system, and the size of the image.
16. An object 50 cm tall is placed on the principal axis of a convex lens. Its 20 cm tall image is formed on the screen placed at a distance of 10 cm from the lens. Calculate the focal length of the lens.
17. An object 20 cm tall is placed on the principal axis of a convex lens. Its 30 cm tall image is formed on the screen placed at a distance of 10 cm from the lens. Calculate the focal length of the lens.
18. An object 30 cm tall is placed on the principal axis of a convex lens. Its 10 cm tall inverted image is formed on the screen placed at a distance of 15 cm from the lens. Calculate the focal length of the lens.
19. An object 3.0 cm high is placed perpendicular to the principal axis of a concave lens of focal length 15.0 cm. The image is formed at a distance of 10.0 cm from the lens. Calculate
(i) distance at which the object is placed and
(ii) size and nature of the image formed.
20. An object 2.0 cm in size is placed 20.0 cm in front of a concave mirror of focal length 10.0 cm. Find the distance from the mirror at which a screen should be placed in order to obtain sharp image. What will be the size and nature of the image formed ?
21. A convex lens has a focal length of 25 cm. Calculate the distance of the object from the lens if the image is to be formed on the opposite side of the lens at a distance of 75 cm from the lens. What will be the nature of the image?
22. A convex lens has a focal length of 30 cm. Calculate at what distance should the object be placed from the lens so that in forms an image at 60 cm on the other side of the lens. Find the magnification produced by the lens in this case.
23. An object 3 cm high is placed at a distance of 9 cm in front of a concave mirror of focal length 18 cm. Find the position, nature and size of the image formed.
24. An object 4 cm high is placed at a distance of 20 cm in front of a convex lens of focal length 12 cm. Find the position, nature and size of the image formed.
25. Find the position, nature and size of the image of an object 3 cm high placed at a distance 6 cm from a concave mirror of focal length 12 cm.
26. Where should an object be placed from a converging lens of focal length 20 cm, so as to obtain a real image of magnification 2?
27. Find the position of the object which when placed in front of a convex mirror produces a virtual image, which is half the size of the object.
28. Find the position of an object which when placed in front of a concave mirror of focal length 20 cm produces a virtual image, which is twice the size of the object.
29. An object is kept in front of a concave mirror of focal length 15 cm. The image formed is three times the size of object. Calculate two possible distances of the object from the mirror.
30. Monochromatic light of wavelength 589 nm is incident from air on a water surface. What are the wavelength, frequency and speed of (a) reflected (b) refracted light? ($n$ of water = 1.33)
31. An object 10 cm long is placed at 15 cm away from a convex lens of focal length 10 cm. Find the position and size of image.
32. (a) State the relation between object distance, image distance and focal length of a spherical mirror.
(b) A concave mirror of focal length 15 cm form an image of an object kept at a distance of 10 cm from the mirror. Find the position nature and size of the image formed by it.
(c) Draw a ray diagram to show the image formed by a concave mirror when an object is placed between pole and focus of the mirror.

# SOLUTIONS

Brief Explanations of Selected Questions

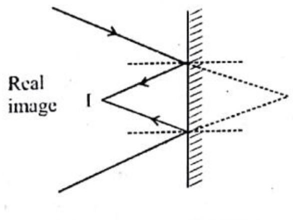
## Exercise 1

### FILL IN THE BLANKS :

(1) positive, negative.
(2) straight lines.
(3) away from, towards
(4) air-glass, glass-air, parallel
(5) focal length
(6) dioptre
(7) equal
(8) inwards, outwards.
(9) concave
(10) pole
(11) front
(12) principal axis
(13) principal focus
(14) concave
(15) lens.
(16) convergence or divergence
(17) convex
(18) 5/4

### TRUE / FALSE

(1) True (2) True (3) True
(4) True (5) True (6) True (7) True
(8) False. Many books says plane mirror always form virtual image but plane mirror can form real image as shown.




(9) True (10) True (11) True
(12) True (13) True (14) False
(15) True (16) False

### MATCH THE FOLLOWING :

(1) (A) $\rightarrow$ q; (B) $\rightarrow$ p; (C) $\rightarrow$ r; (D) $\rightarrow$ p
(2) (A) $\rightarrow$ r; (B) $\rightarrow$ s; (C) $\rightarrow$ q; (D) $\rightarrow$ p

### VERY SHORT ANSWER QUESTIONS :

(1) Concave mirror
(2) No, only one side of the mirror acts as a reflecting surface and the other side is opaque.
(3) We prefer convex mirror for observing the traffic behind us because its field of view is much larger than the plane mirror. However, it gives erroneous idea about the speed of the vehicles behind us.
(4) A ray of light passing through the optical centre of a lens does not suffer any deviation.
(5) Yes, the power of the lens will decrease or the focal length of the lens will increase when it is put in water.
(6) The point on the principal axis at which all the rays parallel and close to the principal axis meet after reflection from the concave mirror.
(7) The path of light is called a ray.
(8) The radius of a plane mirror is infinity.
(9) In a convex mirror, the reflected rays do not actually pass through the focus (F). So, a convex mirror has a virtual principal focus, which is situated behind the mirror.
(10) Light is an electromagnetic wave which does not require a material medium for propagation.
(11) A spherical mirror is the mirror whose reflecting surface is a part of a hollow sphere.
(12) Between P and F (pole and focus).
(13) Convex mirror
(14) The bending of light when it passes from one medium to another is called refraction.
(15) A medium, in which the speed of light is more, is known as optically rarer medium.
(16) A lens is a piece of transparent glass bound by two surfaces out of which atleast one is curved.
(17) One dioptre is the power of a lens whose focal length is 1m.
(18) The linear magnification produced by a lens is equal to the ratio of image distance to the object distance.
(19) The virtual image of a concave mirror is always magnified whereas the virtual image of a convex mirror is diminished.
(20) Frequency remains same on change of medium.
(21) Wavelength decreases on entering a denser medium and wavelength increases on entering a rarer medium.
(22) Refractive index is more for blue light than red light. So the focal length is less for blue light.

### SHORT ANSWER QUESTIONS :

(7) A normal is the line drawn perpendicular to the reflecting surface at the point of incidence.
(8) A focal plane is an imaginary plane perpendicular to the principal axis and passes through the focus of the lens.
(9) Magnification, $m = -3$ (since image is real)
Object distance, $u = -10$ cm.
Image distance, $v = ?$
We know that magnification for the mirror

$$m = -\frac{v}{u} \text{ or } -3 = -\frac{v}{-10} \text{ or } v = -30\text{ cm.}$$

**(10)** Refractive index of glass = $\dfrac{\text{Speed of light in air}}{\text{Speed of light in glass}}$

or $1.5 = \dfrac{3\times10^8}{\text{Speed of light in glass}}$

or Speed of light in glass = $\dfrac{3\times10^8}{1.50}\,\text{ms}^{-1} = 2\times10^8\,\text{ms}^{-1}$

The speed of light in glass is $2\times10^8\,\text{ms}^{-1}$.

**(11)** Diamond has a very high refractive index of 2.42. Larger the refractive index of a medium, greater is the bending of light when it enters the medium from air obliquely.

**(12)** Focal length, $f = -2\text{m}$ (concave lens)

Power, $P = \dfrac{1}{f\ (\text{in } m)} = \dfrac{1}{-2} = -0.5\,D$

**(13)** The power of this lens has negative (–) sign, so it is a concave lens.

Power, $P = \dfrac{1}{f\ (\text{in } m)}$

$\therefore\quad -2.0 = \dfrac{1}{f}\quad$ or $\quad f = \dfrac{1}{-2.0}\,m$

or $f = -0.50\,\text{m}$

$\therefore$ Focal length, $f = -0.50\,\text{m}$

**(14)** The word AMBULANCE on the hospital vans is written in the form of its mirror image as because any vehicle, which is ahead of ambulance van, we can see the laterally inverted alphabets correctly from his rear-view mirror and make way for it to pass through and enable it to reach the hospital quickly.

**(15)** Here, the focal length of the lens is given in cm. We should first convert the focal length into m.

Now, $10\,\text{cm} = \dfrac{10}{100}\,\text{m} = 0.1\text{m}$

So, focal length, $f = 0.1\,\text{m}$ (a convex lens has positive focal length)

Now, $P = \dfrac{1}{f\ (\text{in metres})}$

We get, $P = \dfrac{1}{0.1}\quad$ or $\quad P = \dfrac{1\times10}{1}$

Thus, power $P = +10$ dioptre (or $+10\,D$)

The plus sign with the power indicates what it is a converging lens (or convex lens)

**(18)** The image will be virtual and erect if $\mu < F$, the image will be smaller if $\mu > 2F$ and larger if $\mu < 2F$.

**(19)** Put a block either to the rays of light coming along the edge or the middle of the lens.

**(20)** $\mu_r < \mu_g < \mu_y$.

**(21)** 1 : 1

**(22)** Given : Object distance $u = -12$ cm.

Magnification $m = -4$.

We know that, $m = -\dfrac{v}{u} = \dfrac{h'}{h}$

$\therefore\quad -4 = -\dfrac{v}{u} = -\dfrac{v}{(-12)}\quad \therefore\quad v = -48\,\text{cm}$

So, image is formed at a distance of 48 cm on the same side of object.

**(23)** Given : ${}_{air}n_{ice} = 1.31$, ${}_{air}n_{rock} = 1.54$

${}_{ice}n_{rock} = \dfrac{{}_{air}n_{ice}}{{}_{air}n_{ice}} = \dfrac{1.54}{1.31} = 1.18.$

**(24)** $n_{ga} = 1.5$, $v_a = 3.0\times10^8\,ms^{-1}$, $v_g = ?$

$n_{ga} = \dfrac{v_a}{v_g}\ \Rightarrow\ v_g = \dfrac{v_a}{n_{ga}} = \dfrac{3\times10^8}{1.5}$

$\therefore$ Speed of light in glass $v_g = 2\times10^8\,\text{ms}^{-1}$.

**(25)** Convex lens increases its focal length, while the focal length of concave mirror remains same.

## LONG ANSWER QUESTIONS :

**(2)** Radius of curvature of convex mirror, $R = 30\,\text{cm}$.

$\therefore$ Focal length of convex mirror, $f = \dfrac{R}{2} = \dfrac{30\,\text{cm}}{2} = 15\text{cm}$.

Now $h = 5\,\text{cm}$, $u = -20\,\text{cm}$, $v = ?$, $h' = ?$

Using the mirror formula $\dfrac{1}{f} = \dfrac{1}{v} + \dfrac{1}{u}$, we have

$\dfrac{1}{v} = \dfrac{1}{f} - \dfrac{1}{u} = \dfrac{1}{15} - \dfrac{1}{-20} = \dfrac{1}{15} + \dfrac{1}{20} = \dfrac{4+3}{60}$

$v = \dfrac{60}{7} = 8.6\,\text{cm}.$

Thus, image is formed at a distance of 8.6 cm behind the convex mirror. The image is virtual and erect.

$m = \dfrac{h'}{h} = -\dfrac{v}{u}$

$\dfrac{h'}{5} = -\dfrac{8.6}{-20} \Rightarrow h' = \dfrac{8.6}{20}\times5 = 2.15\,\text{cm}.$

**(3)** For convex mirror, we have given

$u = -10\,\text{m}$, $R = 2.0\,\text{m}$

So, $f = \dfrac{R}{2} = \dfrac{2.0\text{m}}{2} = 1.0\,\text{m}$

Using the mirror formula, $\dfrac{1}{u} + \dfrac{1}{v} = \dfrac{1}{f}$

We get $\dfrac{1}{v} = \dfrac{1}{f} - \dfrac{1}{u} = \dfrac{1}{1.0} + \dfrac{1}{10} = \dfrac{11}{10}$

or $v = \dfrac{10}{11} = 0.9\,\text{m}$

Thus, the car would appear at 0.9 m from the convex mirror. We know that $m=-\frac{v}{u}=\frac{-\frac{10}{11}}{-10}=\frac{1}{11}$

Thus, size of the image of the car will be $\frac{1}{11}$ times smaller the actual size of the car through the convex mirror.

**(4)** According to cartesian sign convention,
$u=-90$ cm, $f=-30$ cm.

We have the formula $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$

$$\therefore \quad \frac{1}{v}-\frac{1}{90}=-\frac{1}{30}$$

or $$\frac{1}{v}=-\frac{1}{30}+\frac{1}{90}=\frac{-3+1}{90}=\frac{-2}{90}$$

$\therefore \quad v=-45$ cm.

Negative sign means that a real image is formed 45 cm from the mirror on the same side as the object.

**(5)** 10D, 0.1 **(6)** 60 cm. **(7)** −10 cm, −10 D

**(8)** (i) Focal length of concave mirror remains same, since it is independent of the wavelength of light.
(ii) When wavelength is increased, refractive index of glass for the particular colour decreases. Since focal length depends on μ, the focal length increases.

**(9)** Mirror formula is, $\frac{1}{f}=\frac{1}{v}+\frac{1}{u}$ where $u$, $v$ and $f$ are object distance, image distance and focal length.

$$\frac{1}{v}=\frac{1}{f}-\frac{1}{u}$$

Focal length and object distance are both −*ve* for concave mirror.
It is given $u<f$,

$\therefore \quad \frac{1}{v}$ becomes $\frac{-1}{f}+\frac{1}{u}$ and is positive.

$v$ becoming +ve denotes a virtual image.

**(10)** $f=-20$ cm, $h_0=5$ cm, $v=-15$ cm.

Using $\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$ we get,

$$\frac{1}{u}=\frac{1}{v}-\frac{1}{f}=\frac{1}{-15}-\frac{1}{(-20)}$$

$$\frac{1}{u}=\frac{-20+15}{300}=-\frac{5}{300}$$

$u=-60$ cm.

Since $m=\frac{h_1}{h_0}=\frac{v}{u}$ we get,

$$h_1=\frac{v}{u}.h_0=\frac{(-15)}{(-16)}\times 5=\frac{5}{4}$$

Image is enlarged and virtual.

# Exercise 2

## MULTIPLE CHOICE QUESTIONS :

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | b | 10 | a | 19 | d | 28 | d | 37 | c | 46 | c |
| 2 | a | 11 | a | 20 | d | 29 | a | 38 | b | 47 | a |
| 3 | c | 12 | c | 21 | d | 30 | a | 39 | d | 48 | c |
| 4 | d | 13 | b | 22 | b | 31 | a | 40 | c | 49 | c |
| 5 | d | 14 | c | 23 | c | 32 | a | 41 | c | 50 | a |
| 6 | d | 15 | b | 24 | a | 33 | c | 42 | b | | |
| 7 | c | 16 | a | 25 | a | 34 | b | 43 | a | | |
| 8 | a | 17 | d | 26 | a | 35 | c | 44 | b | | |
| 9 | c | 18 | d | 27 | d | 36 | b | 45 | d | | |

**(4)** (d) $\frac{\sin i}{\sin r}=\mu$. Angle between refractive & reflective waves
$=180°-(i+r)=90° \Rightarrow i+r=90°$
$r=90°-i$

$$\therefore \mu=\frac{\sin i}{\sin(90-i)}=\frac{\sin i}{\cos i}=\tan i \Rightarrow i=\tan^{-1}(\mu)$$

**(5)** (d) For a spherical lens $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$

For convex lens. $u=-f/2$ and f is + ve

$$\therefore \frac{1}{v}=\frac{1}{f}+\frac{1}{u}+\frac{1}{f}=+\frac{1}{f}-\frac{2}{f} \quad \therefore v=-f$$

## MORE THAN ONE CORRECT :

| | | | | | |
|---|---|---|---|---|---|
| 1 | a,b,c | 11 | a,b | 21 | a,b,c |
| 2 | a,b,c | 12 | a,c | 22 | a,b |
| 3 | a,c | 13 | a,b,d | 23 | a,b,c |
| 4 | a,c,d | 14 | b,c,d | 24 | a,b |
| 5 | b,c | 15 | a,c,d | 25 | a,d |
| 6 | b,c | 16 | a,c,d | 26 | c,d |
| 7 | a,c,d | 17 | a,b,c,d | 27 | a,b,c |
| 8 | a,c,d | 18 | a,c,d | 28 | a,c,d |
| 9 | a,c,d | 19 | a,b,d | 29 | a,b,c |
| 10 | a,b | 20 | a,b,c | 30 | a,c,d |

## FILL IN THE PASSAGE :

**I.** 1. away 2. greater than
3. 90° 4. critical angle
5. reflected 6. total internal reflection

**II.** 1. Two
2. convex lens
3. concave lens
4. thicker
5. thinner

III. 1. optical centre
2. positive
3. negative
4. focal length
5. concave lens

## Passage Based Questions :

**Passage I**

(1) (a) (2) (c) (3) (b)

**Passage II**

(1) (a) Power of convex lens $= \frac{100}{20} = +5D$

(2) (c) Power of concave lens $= \frac{100}{60} = -1.67D$

(3) (b) Power of combination $= P_1 + P_2 = +5 + (-1.67) = +3.33\,D$

$\therefore$ Focal length of combination $= \frac{100}{3.33} = +30$ cm

**Passage III**

(1) Object size $h_0 = 5.0$ cm, $f = 20$ cm,
Object distance $u = -30$ cm

Since, $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

(a) $\frac{1}{v} = \frac{1}{f} + \frac{1}{u}$

Then $\frac{1}{v} = \frac{1}{20} + \frac{1}{-30} = \frac{1}{60}$ $\therefore$ $v = +60$ cm

Positive sign of $v$ shows that image is formed at a distance of 60 cm to the right of the lens.
Therefore image is real and inverted.

(2) (a) Since, $m = \frac{h'}{h} = \frac{v}{u}$

$\therefore$ $h' = \frac{v \times h}{u} = \frac{60 \times 5}{-30} = -10$ cm

So, size of image is twice the size of object.

(3) (a) Power $= \frac{1}{f} = \frac{1}{0.2m} = +5D$

## Assertion & Reason :

(1) (c) (2) (d) (3) (a) (4) (a)
(5) (d) (6) (b) (7) (c) (8) (b)
(9) (c)
(10) (c) An image is a plane mirror is virtual and it can be photographed.
(11) (c) Object is placed between $F$ and $2F$ of objective lens.
(12) (b) (13) (b) (14) (a) (15) (a)
(16) (c) (17) (a)

## Multiple Matching Questions :

(1) (A) → q; r (B) → s; (C) → p; (D) → p, r
(2) (A) → p, q, r; (B) → p, q, r; (C) → p, q, t; (D) → p, q

## Hots Subjective Questions :

(1) For convex mirror, we have given
$u = -10$ m, $R = 2.0$ m

So, $f = \frac{R}{2} = \frac{2.0\text{ m}}{2} = 1.0$m

Using the mirror formula, $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$

We get $\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{1.0} + \frac{1}{10} = \frac{11}{10}$

or $v = \frac{10}{11} = 0.9$ m

Thus, the car would appear at 0.9 m from the convex mirror.

We know that $m = -\frac{v}{u} = \frac{-\frac{10}{11}}{-10} = \frac{1}{11}$

Thus, size of the image of the car will be $\frac{1}{11}$ times smaller the actual size of the car through the convex mirror.

(2) $u = -15$ cm, $f = +30$ cm (for convex mirror, $f$ is +ve)

The mirror formula is, $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$ $\therefore$ $\frac{1}{v} = \frac{1}{f} - \frac{1}{u}$

Substituting the values of $u$ and $f$ in the above formula we have $\frac{1}{v} = \frac{1}{30} - \left(-\frac{1}{15}\right) = \frac{1}{30} + \frac{1}{15} = \frac{1+2}{30} = \frac{1}{10}$

$\therefore$ $v = +10$ cm.

(3) Here, sine of angle of incidence (sin $i$) = 0.866
and sine of angle of refraction (sin $r$) = 0.707

Now, we have $\mu = \frac{\sin i}{\sin r} = \frac{0.866}{0.707} = 1.22$

Hence, the refractive index of the medium is 1.22.

(4) Since lens is convex, therefore $f$ is positive.
Given $u = -20$ cm, $f = +12$ cm, $h = 3$ cm, $v = ?$, $h' = ?$
Since formula for a lens is

$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$, $\frac{1}{v} - \frac{1}{-20} = \frac{1}{12}$

$\Rightarrow \frac{1}{v} + \frac{1}{20} = \frac{1}{12}$ $\Rightarrow \frac{1}{v} = \frac{1}{12} - \frac{1}{20}$

$\Rightarrow \frac{1}{v} = \frac{5-3}{60} = \frac{1}{30}$ $\Rightarrow v = 30$ cm.

Since '$v$' is positive, the image is located on the other side of the lens.

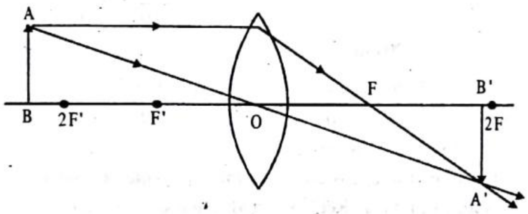
$$m=\frac{v}{u}=\frac{+30}{-20}=-1.5$$

Since m is negative and greater than 1, the image is real, inverted and larger than the object.

$$m=\frac{h'}{h}\Rightarrow -1.5=\frac{h'}{3} \text{ or } h'=-4.5\text{ cm.}$$

Thus the image is 30 cm from the convex lens, located on the other side of the object. It is real inverted and 4.5 cm high.

**(5)** Since the image is real and diminshed, the lens must be convex and the object must be placed beyond $2F$.




Given : $v=+18$ cm,

$\frac{h'}{h}=\frac{-4}{5}$, $f=?$ [$\because m=\frac{h'}{h}$ is negative for real image]

We have, $m=\frac{h'}{h}=\frac{v}{u}$

$\therefore \frac{v}{u}=\frac{-4}{5}$ or $4u=-5v$ or $4u=-5\times 18$ cm

$\therefore u=-22.5$ cm.

Now focal length is given by :

$$\frac{1}{f}=\frac{1}{v}-\frac{1}{u}=\frac{1}{18}-\frac{1}{-22.5}=\frac{1}{18}+\frac{1}{22.5}=\frac{9}{90}$$

$\therefore f=10$ cm.

**(6)** A concave lens always forms a virtual, erect image on the same side of the object.

Image distance $v=-10$ cm

Focal length $f=-15$ cm,

Object distance $u=?$

Since $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$ or $\frac{1}{u}=\frac{1}{v}-\frac{1}{f}$

$$\frac{1}{u}=\frac{1}{-10}-\frac{1}{(-15)}=-\frac{1}{10}+\frac{1}{15}$$

$$\frac{1}{u}=\frac{-3+2}{30}=\frac{1}{-30} \text{ or } u=-30\text{ cm.}$$

Thus, the object distance is 30 cm.

Magnification, $m=\frac{v}{u}$ or $m=\frac{-10\text{ cm}}{-30\text{ cm}}=\frac{1}{3}=+0.33$

**(7)** A very small head $\rightarrow$ Convex mirror

A fat body $\rightarrow$ Concave mirror

Legs of normal size $\rightarrow$ Plane mirror

**(8)** $^a\mu_g=\frac{\text{Real depth}}{\text{Apparent length}}$ or $1.54=\frac{3.0\text{ cm}}{\text{Apparent length}}$

$\therefore$ Apparent depth $=\frac{3.0}{1.54}=1.94$ cm.

$\therefore$ Height through which image is raised $=(3-1.94)=1.06$ cm.

**(9)** Let real thickness of glass $=x$

$\therefore$ Apparent thickness $=(x-8\text{ mm})$

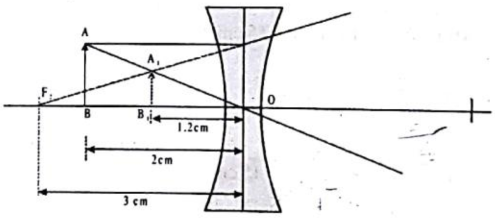
We know $\mu=\frac{\text{Real depth}}{\text{Apparent depth}}$ or $1.5=\frac{x}{x-8\text{ mm}}$

$\therefore 1.5x-12\text{ mm}=x$ $\quad\therefore x=24$ mm

**(10)** Let the scale be 5 cm = 1 cm

$\therefore$ Size of the object = 5 cm = 1 cm

$\therefore$ Distance of the object from the lens = 10 cm = 2 cm




$\therefore$ Focal length of the lens = 15 cm = 3 cm

On constructing the ray diagram, it is found

$\therefore$ size of the image $=A_1B_1=0.6\text{ cm}=0.6\times 5\text{ cm}=3.0$ cm

Distance of the image from lens $=OB_1=1.2\text{ cm}=1.2\times 5\text{ cm}$ $=6$ cm

Nature : Image is virtual, erect and diminished.

**(11)**

**(12)** (a) real inverted reduced (b) real, inverted, same size
(c) no image is formed (d) virtual, erect, enlarged

**(13)** (a) virtual, erect, reduced (b) virtual, erect, reduced
(c) virtual, erect, reduced (d) virtual, erect, reduced

**(14)** (a) 7.5 cm. (b) 48 cm.

**(15)** (a) (i) +30 cm, −22 cm, (ii) −20 cm, −42 cm, (b) 0.98 cm.

**(16)** $h_0=50$ cm, $h_i=20$ cm, $v=10$ cm.

Using $m=\frac{h_1}{h_0}=\frac{v}{u}$, we get

With sign convention,

$$u = v\frac{h_0}{h_1} = 10 \times \frac{50}{(-20)} = -25 \text{ cm}.$$

Using $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$ we get,

$$\frac{1}{f} = \frac{1}{10} - \frac{1}{-25} = \frac{25+10}{250}$$

$$f = \frac{250}{35} = 7.14 \text{ cm}.$$

**(17)** $h_0 = 20$ cm, $h_1 = -30$ cm, $v = 10$ cm

$$m = \frac{h_1}{h_0} = \frac{(-30)}{20} = \frac{v}{u}$$

$$\therefore\ u = -\frac{10 \times 2}{3} = -\frac{20}{3} \text{ cm}.$$

Using $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$ we get,

$$\frac{1}{f} = \frac{1}{10} - \frac{1}{\left(-\frac{20}{3}\right)} = \frac{1}{10} + \frac{3}{20} = \frac{5}{20} = \frac{1}{4}$$

$$f = +4 \text{ cm}.$$

**(18)** $h_0 = 30$ cm, $h_1 = -10$ cm, $v = 15$ cm

Using $m = \frac{h_1}{h_0} = \frac{v}{u}$, we get

$$\therefore\ u = v\frac{h_0}{h_1} = 15 \times \frac{30}{-10} = -45 \text{ cm}.$$

Using $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$ we get,

$$\frac{1}{f} = \frac{1}{15} - \frac{1}{-45} = \frac{3+1}{45} = \frac{4}{45}$$

$$f = \frac{45}{4} = 11.25 \text{ cm}.$$

**(19)** Here $h = 3.0$ cm, $f = -15$ cm, $v = -10.0$ cm

(i) From lens formula

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

$$\therefore\ \frac{1}{u} = \frac{1}{v} - \frac{1}{f} = \frac{1}{-10} - \frac{1}{-15}$$

$$\frac{1}{u} = \frac{1}{15} - \frac{1}{10} = -\frac{1}{30} \quad \therefore\ u = -30 \text{ cm}.$$

(ii) $m = \frac{h'}{h} = \frac{v}{u}$

$$\therefore\ h' \frac{v}{u} \times h \frac{-10}{-30} \times 3 = +1.0$$

From (i) and (ii), it is clear that image is formed on the same side of object placed at a distance of 30 cm and image is virtual, erect and of same size.

**(20)** For a concave mirror

Given : $h = 2$ cm, $u = -20$ cm, $f = -10$ cm

$v = ?\ h' = ?$

From mirror equation, we know that

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{-10} - \frac{1}{-20} = -\frac{1}{10} + \frac{1}{20}$$

$$= \frac{-2+1}{20} = \frac{-1}{20}$$

$\therefore\ v = -20$ cm.

Also $m = \frac{h'}{h} = -\frac{v}{u} \Rightarrow h' = -\frac{(-20) \times 2}{-20} = -2$

$\therefore$ Image size $h' = -2$ cm.

Position of image is 20 cm on the same side of object.

Nature of image : Real, inverted, same size ($h' = h$).

**(21)** Focal length of convex lens, $f = +25$ cm image distance, $v = +75$ cm

From lens formula

$$\frac{1}{u} = \frac{1}{v} - \frac{1}{u}$$

$$\therefore\ \frac{1}{u} = \frac{1}{v} - \frac{1}{f} = \frac{1}{75} - \frac{1}{25} = -\frac{2}{75}$$

$$\Rightarrow u = -\frac{75}{2} = -37.5 \text{ cm}$$

Negative sign shows that image is real.

**(22)** Given : For convex lens

$f = +30$ cm, $u = ?$, $v = +60$ cm, $m = ?$

From lens formula

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \qquad \therefore\ \frac{1}{30} = \frac{1}{60} - \frac{1}{u}$$

$$\Rightarrow \frac{1}{u} = \frac{1}{60} - \frac{1}{30} = \frac{1-2}{60}$$

$$\frac{1}{u} = -\frac{1}{60} \qquad \therefore\ u = -60 \text{ cm}.$$

So, the object should be placed at a distance of 60 cm to the left of the lens.

Magnification produced by lens,

$$m = \frac{h'}{h} = \frac{v}{u} = \frac{+60}{-60} = -1$$

Hence, real, inverted and same size image is obtained.

**(23)** For a concave mirror,

$h = +3$ cm, $u = -9$ cm, $f = -18$ cm, $v = ?$, $h' = ?$

From mirror equation

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u} \quad \therefore \frac{1}{v} = \frac{1}{f} - \frac{1}{u}$$

$$= \frac{1}{-18} - \frac{1}{-9} = -\frac{1}{18} + \frac{1}{9} = \frac{1}{18} \quad \therefore v = +18 \text{ cm.}$$

i.e., image is formed behind the mirror at a distance of 18 cm. It is virtual.

Also, magnification $m = \frac{h'}{h} = -\frac{v}{u}$

$$\therefore \frac{h'}{+3} = -\frac{+18}{-9} = +2 \quad \therefore h' = +6 \text{ cm}$$

So, image is erect and twice the size of object.

**(24)** Given : $h = +3.0$ cm, $u = -20$ cm, $f = +12$ cm, From lens formula

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \Rightarrow \frac{1}{12} = \frac{1}{v} - \frac{1}{-20}$$

$$\therefore \frac{1}{v} = \frac{1}{12} - \frac{1}{20} = \frac{5-3}{60} = \frac{2}{60} = \frac{1}{30}$$

$\therefore v = +30$ cm.

Also, $m = \frac{h'}{h} = \frac{v}{u}$

$$\Rightarrow \frac{h'}{3} = \frac{+30}{-20} = -\frac{3}{2} \quad \therefore h' = -\frac{9}{2} = -4.5 \text{ cm}$$

Therefore, Position of image : 30 cm to the right of the lens

Nature of image : real, inverted

Size of image : enlarge (4.5 cm).

**(25)** $h_0 = 3$ cm, $u = -6$ cm, $f = -12$ cm

Mirror formula : $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$

$$\frac{1}{-12} = \frac{1}{v} + \frac{1}{-6}$$

$$\frac{1}{v} = \frac{-1}{12} + \frac{1}{6} = \frac{-1+2}{12} \; ; \; \frac{1}{v} = \frac{1}{12}$$

$\therefore \quad v = +12$ cm

$$m = \frac{h'}{h} = -\frac{v}{u}$$

$$h' = -\frac{v}{u} \times h = \frac{-12}{-6} \times 3 = +6$$

Position : image is formed behind the mirror at a distance of 12 cm.

Nature : virtual, erect, enlarged

Size of image : Twice the size of object.

**(26)** $f = +20$ cm, Since image is real, $m = -2$

Using, $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$ and $m = \frac{v}{u}$

we get, $m = \frac{f}{f+u} \Rightarrow -2 = \frac{20}{20+u}$

$-40 - 2u = 20 \quad \Rightarrow -2u = 60 \Rightarrow u = -30$ cm.

**(27)** Convex mirror, $m = 1/2$

Image is virtual, $\therefore m = +\frac{1}{2} \Rightarrow -\frac{v}{u} = \frac{1}{2}$

Therefore from $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$ we get

$$\frac{1}{f} = \frac{2}{u} + \frac{1}{u} = -\frac{1}{u} \quad \text{i.e., } u = -f$$

Object has to be at a distance equal to focal length.

**(28)** $f = -20$ cm. Since image is virtual $m = +2$.

Using $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$ and $m = -\frac{v}{u}$

we get $m = \frac{f}{f-u} \quad \therefore \quad 2 = \frac{-20}{-20-u}$.

$-40 - 2u = -20 \Rightarrow 2u = -20 \Rightarrow \quad u = -10$ cm.

**(29)** $f = -15$ cm, $h_i = 3h_0$

For Real Image,

$$m = -\frac{v}{u} = -3 \therefore v = 3u$$

using $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$, we get, $\frac{1}{-15} = \frac{1}{3u} + \frac{1}{u}$

$\Rightarrow u = -20$ cm.

For Virtual Image,

$$m = -\frac{v}{u} = +3 \Rightarrow v = -3u$$

using $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$

we get, $\frac{1}{-15} = \frac{1}{(-3u)} + \frac{1}{u} \Rightarrow u = -10$ cm.

The two possible positions are 10 cm and 20 cm in front of concave mirror.

**(30)** $\lambda_{air} = 589\ nm = 589 \times 10^{-9}\ m$

Refractive index of water $= \mu = 1.33$

(a) Reflected light will have same wavelength, frequency and velocity.

$\therefore \lambda = 589\ nm, c = 3 \times 10^8$ ms$^{-1}$

$$f = \frac{c}{\lambda} = \frac{3 \times 10^8}{589 \times 10^{-9}} = 5.09 \times 10^{-3+8+9} = 5.09 \times 10^{14}\ Hz$$

(b) The frequency is same with refracted light. But, velocity and wavelength vary.

Since, $\mu = \frac{c}{v}$,

velocity in water $= \frac{3\times10^8}{1.33} = 2.25\times10^8\ ms^{-1}$

Since, $\mu = \frac{\lambda}{\lambda'}$,

wavelength in water is $\lambda' = \frac{\lambda}{\mu} = \frac{589\times10^{-9}}{1.33} = 442$ nm.

**(31)** $h_0 = 10$ cm, $u = -15$ cm, $f = +10$ cm

using $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$, we get,

$$\frac{1}{v} = \frac{1}{10} + \frac{1}{-15} = \frac{15-10}{150} = \frac{5}{150}$$

$$v = \frac{150}{5} = 30\,\text{cm}$$

Image formed is real and is at a distance of 30 cm.

$$\frac{h_1}{h_0} = \frac{v}{u} = \therefore h_1 = \frac{30}{-15}\times10 = -20$$

Image is inverted since $h_1$ is $-ve$.

**(32)** (a) The relation between object distance, image distance and focal length of a spherical mirror is given by

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$$

where $f$ = Focal length of spherical mirror
$v$ = Image distance, $u$ = Object distance.
This relation is called mirror equation.

(b) For a concave mirror

Given : $f = -15$ cm, $u = -10$ cm, $v = ?$, $m = ?$

From mirror equation

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$$

$$\therefore \frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{-15} - \frac{1}{-10} = \frac{-1}{15} + \frac{1}{10}$$

$$= \frac{-10+15}{150} = +\frac{5}{150} = +\frac{1}{30} \quad \therefore v = +30\,\text{cm}.$$

Also, Magnification, $m = -\frac{v}{u} = -\frac{+30}{-10} = 3$.

Hence, the image is formed at a distance of 30 cm behind the mirror.

Nature of image : Virtual, erect.

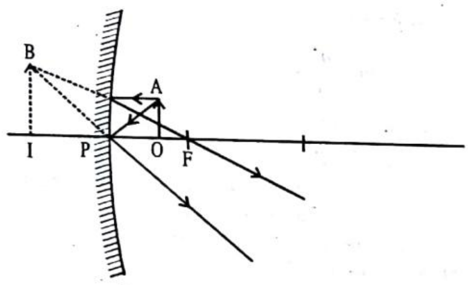
Size of image : Magnified, i.e., thrice the size of object.

(c) Position of object : Between pole and focus

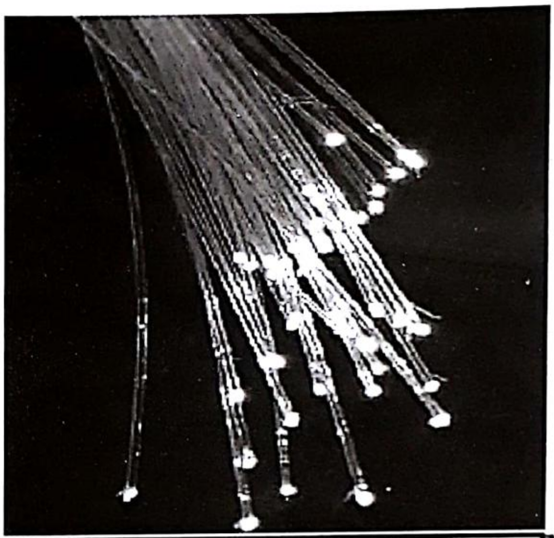
Mirror : Concave.

Position of image : Behind the mirror.

Nature of image : Virtual, enlarged and erect.



chapter 2



# HUMAN EYE AND COLOURFUL WORLD

## Introduction

Light enables us to see things. But light alone can't show us things visible. It does so with the help of 'eyes'. When eyes get defective, some visual aids are required. These aids can be in the form of spectacles. To see things bigger than their actual size, optical instruments are used. With the help of these instruments we can see distant objects like stars, sun, moon and other celestial objects very clearly. We can also see very small things very clearly with their aid.

Light makes our world colourful. When light passes through a prism, a very beautiful band of seven colours is obtained on a nearby screen. When sun light falls on water droplets just after raining, a beautiful rainbow is observed.

This chapter is an attempt to provide a description of the eye, its defects and remedies, optical instruments and phenomena which makes our world colourful.

## THE HUMAN EYE

The human eye is the organ which gives us the sense of sight, allowing us to learn more about the surrounding world than we do with any of the other four senses. We use our eyes in almost every activity we perform, whether reading, working, watching television, writing a letter, driving a car, and in countless other ways. Most people probably would agree that sight is the sense they value more than all the rest.

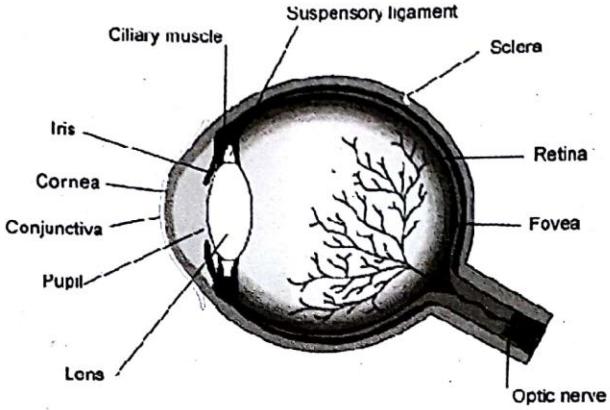



*Fig. 2.1*

The eye allows us to see and interpret the shapes, colors, and dimensions of objects in the world by processing the light they reflect or emit. The eye is able to see in bright light or in dim light, but it cannot see objects when light is absent.

## PROCESS OF VISION

Light waves from an object (such as a tree) enter the eye first through the cornea, which is the clear dome at the front of the eye. The light then progresses through the pupil, the circular opening in the center of the colored iris. Next, the light passes through the crystalline lens, which is located immediately behind the iris and the pupil.

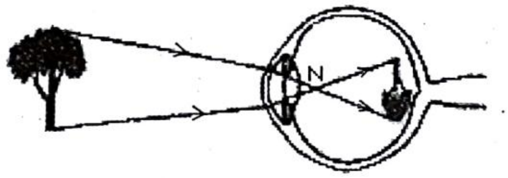



*Fig. 2.2*

Initially, the light waves are bent or converged first by the cornea, and then further by the crystalline lens, to a nodal point (N) located immediately behind the back surface of the lens. At that point, the image becomes reversed (turned backwards) and inverted (turned upside-down).

The light continues through the vitreous humor, the clear gel that makes up about 80% of the eye's volume, and then, ideally, back to a clear focus on the retina behind the vitreous. The small central area of the retina is the macula, which provides the best vision of any location in the retina. If the eye is considered to be a type of camera, the retina is equivalent to the film inside of the camera, registering the tiny photons of light which interact with it.

Within the layers of the retina, light impulses are changed into electrical signals and then sent through the optic nerve, along the visual pathway, to the cortex at the posterior or back of the brain. Here, the electrical signals are interpreted or "seen" by the brain as a visual image. When the light entering the eyes is bright enough, the pupils will constrict (get smaller), due to the pupillary light response.

Actually, then, we do not "see" with our eyes but, rather, with our brains. Our eyes merely are the beginnings of the visual process. You might have experienced that you are not able to see objects clearly for some time when you enter from bright light to a room with dim light. After sometime, however, you may be able to see things in the dim-lit room. The pupil of an eye acts like a variable aperture whose size can be varied with the help of the iris.

When the light is very bright, the iris contracts the pupil to allow less light to enter the eye. However, in dim light the iris expands the pupil to allow more light to enter the eye. Thus, the pupil opens completely through the relaxation of the iris.

## POWER OF ACCOMMODATION

The ability of the lens to change its shape to focus near and distant objects is called accommodation. The table shows how this is done.

| Object | Ciliary muscles | Suspensory ligaments | Muscle tension on lens | Lens shape |
|---|---|---|---|---|
| near | contract | slackened | low | fat |
| distant | relax | stretched | high | thin |

When the eye is relaxed and the interior lens is the least rounded, the lens has its maximum focal length for distant viewing. As the muscle tension around the ring of muscle is increased and the supporting fibres are thereby loosened, the interior lens rounds out to its minimum focal length. The minimum distance, at which objects can be seen most distinctly without strain, is called the least distance of distinct vision. It is also called the near point(N.P.) of the eye. For a young adult with normal vision, the near point is about 25 cm. The farthest point upto which the eye can see objects clearly is called the far point(F.P.) of the eye. It is infinity for a normal eye. Thus a normal eye can see objects clearly that are between 25 cm and infinity.

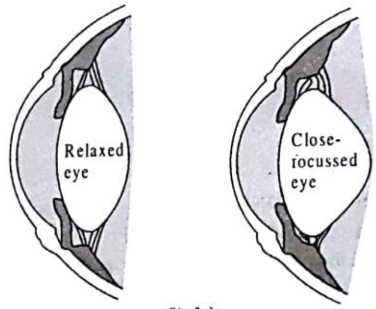



Fig 2.3

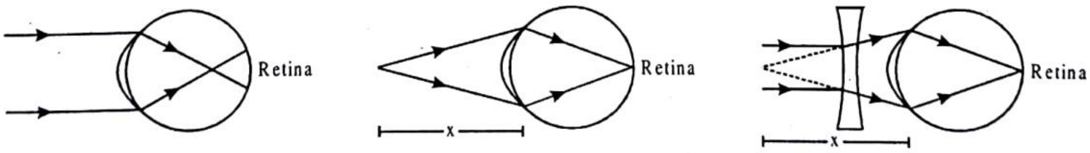
If an eye has the ability to assume a focal length of 1.80 cm (56 diopters) to view objects many miles away as well as the ability to assume a 1.68 cm focal length to view an object 0.25 meters away (60 diopters), then its Power of Accommodation would be measured as 4 diopters (60 diopters – 56 diopters). The healthy eye of a young adult has a Power of Accommodation of approximately 4 diopters. As a person grows older, the Power of Accommodation typically decreases as a person becomes less able to view nearby objects. This failure to view nearby objects leads to the need for corrective lenses.

Many animals can see clearly both in water and on land. Some have extraordinary accommodation ranges, and others have developed other strategies. Cormorants and dippers can vary the refractive power of their lenses by 40-50 diopters, compared to about 16 diopters for an average adolescent human. The increased accommodation is due largely to highly developed sphincter muscles which vary the curvature of the front of the lens. Turtles and otters also have very strong sphincter muscles. Variations in lens geometries are used in various species of birds and fish.

## DEFECTS OF VISION AND THEIR CORRECTION

**NEARSIGHTEDNESS:** If the eyeball is too long or the lens too spherical, the image of distant objects is brought to a focus in front of the retina and is out of focus again before the light strikes the retina. Nearby objects can be seen more easily. Eyeglasses with concave lenses correct this problem by diverging the light rays before they enter the eye. Nearsightedness is called myopia. Myopia most commonly develops in childhood or early teens (between 8 and 14). The risk of developing myopia is increased if there is a family history of it. There may also be a link between myopia and prolonged close-up work, such as reading or sitting close temporary short-sightedness, called pseudomyopia, can be caused by a number of diseases or certain drugs. For example, myopia may be the first sign of type-2 (non insulin-dependent) diabetes. Symptoms of pseudomyopia usually clear up if the underlying cause is treated to the television, although there is little scientific evidence for this.

This defect can be corrected by using a concave lens of suitable focal length. A concave lens diverges the rays coming from the object so that they get focused at the retina.




(a) Defective eye (b) Far point of eye (c) Corrected eye

Fig. 2.4

Let a person can see an object at a maximum distance $x$ (i.e. far point is $x$). Thus, if the eye is to see a distant object clearly, the concave lens should form the virtual image of this distant object at a distance $x$. Thus, the required focal length of the lens is $f = -x$ and power

$$P = \frac{1}{f} = -\frac{1}{x}.$$

## Knowledge ENHANCER

Let a nearsighted person can see upto a maximum distance $x$ and wants to see upto a distance $y$ then

$u = -y;\ \ v = -x;\ \ f = ?$

$$\therefore\ \frac{1}{f} = \frac{1}{v} - \frac{1}{u} = \frac{1}{-x} - \left(-\frac{1}{y}\right) = \frac{1}{y} - \frac{1}{x} = \frac{x-y}{xy}$$

$$\therefore\ f = \frac{xy}{x-y} \text{ and } P = \frac{x-y}{xy}$$

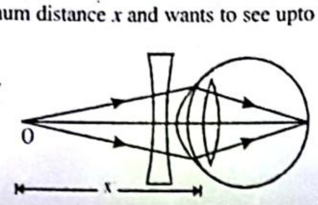



Fig. 2.5 (a)

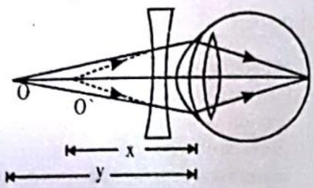



Fig. 2.5 (b)

**FARSIGHTEDNESS:** If the eyeball is too short or the lens too flat or inflexible, the light rays entering the eye — particularly those from nearby objects— will not be brought to a focus by the time they strike the retina. Eyeglasses with convex lenses can correct the problem. Farsightedness is called hypermetropia or hyperopia. Squinting, eye rubbing, lack of interest in school, and difficulty in reading are often seen in children with hyperopia.

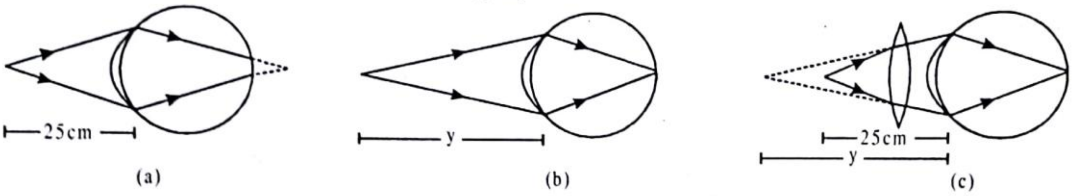



Fig. 2.6

## Knowledge ENHANCER

Let the farsighted eye can see a minimum distance $y$ (i.e. near point of the eye). If the eye is to see clearly an object at the least distance of distinct vision (i.e. at 25 cm ), then the image of the object should form at a distance $y$.

$\therefore\ u = -25$ cm

$v = -y$

$f = ?$

By lens formula,

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} = \frac{1}{-y} - \left(-\frac{1}{25\text{ cm}}\right);\ \frac{1}{f} = \frac{1}{25\text{ cm}} - \frac{1}{y}$$

$$\therefore \text{ Power of lens, } P = \frac{1}{25\text{ cm}} - \frac{1}{y}$$

### PRESBYOPIA ("AFTER 40" VISION)

After age 40, and most noticeably after age 45, the human eye is affected by presbyopia, which results in greater difficulty in maintaining a clear focus at a near distance with an eye which sees clearly at a far away distance. This is due to a lessening of flexibility of the crystalline lens, as well as to a weakening of the ciliary muscles which control lens focusing, both attributable to the ageing process.

Person suffering from presbyopia require bifocal lenses. A common type of bi-focal lenses consists of both concave and convex lenses. The upper portion consists of a concave lens. It facilitates distant vision. The lower part is a convex lens. It facilitates near vision. These days, it is possible to correct the refractive defects with contact lenses or through surgical interventions.

## ASTIGMATISM

Astigmatism is the most common refractive problem responsible for blurry vision. Most of the eyeball's focusing power occurs along the front surface of the eye, involving the tear film and cornea (the clear 'window' along the front of the eyeball).

The ideal cornea has a perfectly round surface. Anything other than perfectly round contributes to abnormal corneal curvature–this is astigmatism. Here's a good way to demonstrate the effects of astigmatism. Look at your reflection in the curved surface of a round soup spoon and compare it with your reflection in an oval teaspoon. The cornea is the transparent layer over the colored part of the eye. It bends (refracts) light rays and helps focus the light onto the retina in the back of the eye so people can see. When the cornea is oblong shaped, it causes light rays to focus on two different points on the retina, instead of just one. As a result, people with significant astigmatism may have distorted or blurry vision.

Astigmatism may cause eye strain and also may be combined with nearsightedness or farsightedness.

Astigmatism can start in childhood or in adulthood.

Cylindrical lens is use to correct astigmatism.

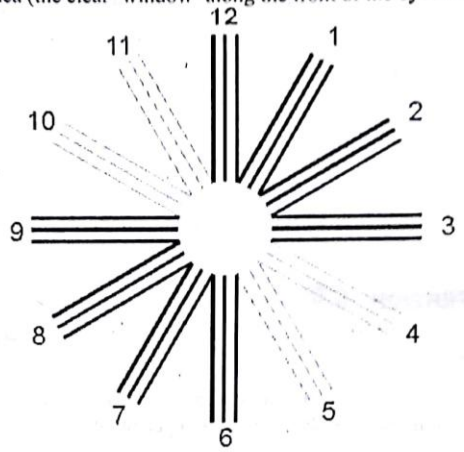



*Fig. 2.7*

If the figure shown was constructed with all the radial lines of equal sharpness and contrast a person without astigmatism would see all these radial lines as perfectly sharp and with the same contrast. The diagram shown has been fudged to illustrate how it might appear to a person with astigmatism.

## CATARACTS

A cataract is a clouding of the lens in the eye. With people age, cataracts grow progressively darker and more dense, preventing light from easily passing through the lens. This results in vision loss.

Patients with cataracts have difficulty seeing in poorly lit environments. Many people also experience increased sensitivity to light and glare, double vision (or "ghost images"), and fading colors (blue may appear green; white may appear dull beige, etc.).

Most cataracts are highly treatable. Cataract surgery is one of the most common surgeries performed in the world with 95% of patients experiencing improved vision if there are no other eye conditions present. During surgery, the doctor removes the clouded lens, and, in most cases, replaces it with an artificial lens, called an intraocular lens (IOL). An IOL is a clear, plastic lens that requires no care and becomes a permanent part of your eye. Thick eyeglass lenses after surgery might not be needed because of the implanted lens.

Complicated cataracts cannot be extracted like normal cataracts because of potential complications such as other eye conditions, lack of vision in the other eye, or health concerns such as diabetes.

## CHECK *Point*

- **Does short-sightedness (myopia) or long-sightedness (hypermetropia) imply necessarily that the eye has partially lost its ability of accommodation? If not, what might cause these defects of vision?**

### SOLUTION

A person with normal ability of accommodation may be myopic or hyperopic due to deflective eye structure. When the eye ball from front to back gets too elongated the "myopic" defect occure, similarly when the eye ball from front to back gets too shortened the "hypermetropia" defect occur.

When the eye ball has normal length but the eyelens loses partially its ability of accommodation, the defect is called "presbyopia" and is corrected in the same manner as myopia or hypermetropia.

## ILLUSTRATION 2.1

A man who wears the corrective lenses of power +3D, has to hold a newspaper at 25 cm away to see the print clearly. How far away would the newspaper have to be, if he took off the corrective lenses and still, wanted a clear vision.

**SOLUTION:**

The corrective lenses have the focal length $f = \frac{1}{P} = \frac{1}{3} m = \frac{100}{3}$ cm

and the lens formula gives $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

$$\Rightarrow \frac{1}{v} - \frac{1}{-25} = \frac{1}{100/3} \Rightarrow \frac{1}{v} = \frac{3}{100} - \frac{1}{25} \Rightarrow v = -100 \text{ cm}$$

which means that the corrective lenses used by man form the clear images at 100 cm of the objects placed at 25 cm, i.e., the near point of man is at 100 cm. Therefore, without wearing the corrective lenses the man must hold the newspaper at 100 cm for the clear vision.

**ILLUSTRATION–2.2**

What should be the focal length of corrective lenses required by a person for reading a book, if his near point is at 90 cm?

**SOLUTION:**

The book is kept at the least distance of distance vision $D = 25$ cm, i.e., $u = -25$ cm and corrective lenses used form the clear images at 90 cm, which is the near point of person, i.e., $v = -90$ cm. Therefore, according to the lens formula, we have

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

$$\Rightarrow \frac{1}{-90} - \frac{1}{-25} = \frac{1}{f} \Rightarrow \frac{1}{f} = \frac{-5+18}{18 \times 25} \Rightarrow f = 34.6 \text{ cm}$$

## REFRACTION OF LIGHT THROUGH A PRISM

Prism is a transparent medium bounded by any number of surfaces in such a way that the surface on which light is incident and the surface from which light emerges are plane and non-parallel.

Consider a triangular glass prism. It has two triangular bases and three rectangular lateral surfaces. These surfaces are inclined to each other. The angle between its two lateral faces is called the angle of the prism. In figure you can see the incident ray, the refracted ray inside the prism and the emergent ray. You may note that a ray of light is entering from air to glass at the first surface. The light ray on refraction has bent towards the normal. At the second surface, the light ray has entered from glass to air. Hence it has bent away from the normal.

The peculiar shape of the prism makes the emergent ray bend at an angle to the direction of the incident ray. This angle is called **the angle of deviation.** It's not only the shape that matters but importantly difference of refractive index of prism material from surrounding makes ray to deviate, if glass prism is placed in a fluid with same refractive index as that of glass ray will pass without deviation.

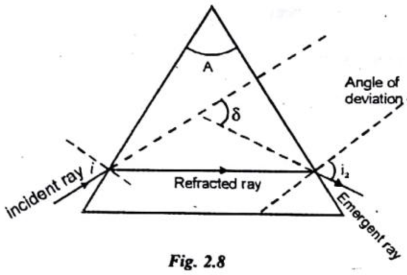



*Fig. 2.8*

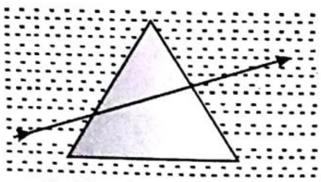


*Fig. 2.8 (a) Light ray is not bent if glass is in fluid of the same index of refraction*

**Activity:**
- Fix a sheet of white paper on a drawing board using drawing pins.
- Place a glass prism on it in such a way that it rests on its triangular base. Trace the outline of the prism using a pencil.
- Draw a straight line *PE* inclined to one of the refracting surfaces, say *AB*, of the prism.
- Fix two pins, say at points *P* and *Q*, on the line *PE* as shown in Figure.
- Look for the images of the pins, fixed at *P* and *Q*, through the other face *AC*.
- Fix two more pins, at points *R* and *S*, such that the pins at *R* and *S* and the images of the pins at *P* and *Q* lie on the same straight line.

- Remove the pins and the glass prism.
- The line *PE* meets the boundary of the prism at point *E* (see Fig. 2.9). Similarly, join and produce the points *R* and *S*. Let these lines meet the boundary of the prism at *E* and *F*, respectively. Join *E* and *F*.
- Draw perpendiculars to the refracting surfaces *AB* and *AC* of the prism at points *E* and *F*, respectively.
- Mark the angle of incidence ($\angle i$), the angle of refraction ($\angle r$) and the angle of emergence ($\angle i'$) as shown in Fig. 2.9

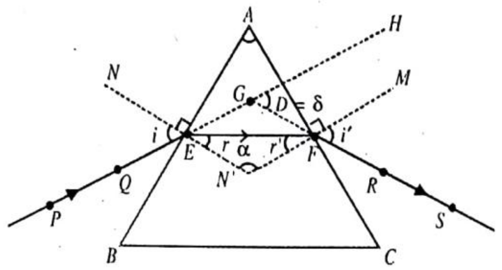



*Fig. 2.9 : Refraction of light through a triangular glass prism*

*PE* – Incident ray, $\angle i$ – Angle of incidence, *EF* – Refracted ray, $\angle r$ – Angle of refraction, *FS* – Emergent ray, $\angle i'$ – Angle of emergence, $\angle A$ – Angle of the prism, $\angle D$ – Angle of deviation.

## ANGLE OF DEVIATION (δ), IN TERMS OF ANGLE OF PRISM (A), $\angle i$ AND $\angle i'$

The angle between the emergent ray and incident ray is called angle of deviation (δ).

In quadrilateral, (see above activity) the sum of its four angles should be 360°

$\therefore \angle AEN' + \angle AFN' + \angle A + \angle \alpha = 360°$

$\therefore 180° + \angle A + \angle \alpha = 360°$ or $\angle A + \angle \alpha = 180°$ ........... (1)

In $\Delta EN'F$, $\angle r + \angle r' + \angle \alpha = 180°$ ........... (2)

From (1) & (2), $\angle A = \angle r + \angle r'$ ........... (3)

In $\Delta GEF$, $\angle \delta$ = exterior angle

$\therefore \angle \delta = (\angle i - \angle r) + (\angle i' - \angle r')$

$\angle \delta = (\angle i + \angle i') - (\angle r + \angle r')$ or $\delta = (i + i') - A$ .......... (4)

## ANGLE OF MINIMUM DEVIATION ($\delta_{min}$)

For each angle of incidence *i*, there is a corresponding angle of deviation δ. As we increase the angle of incidence from zero onwards, the corresponding angle of deviation first decreases, then takes a minimum value whereafter it starts increasing. Let us find out the magnitude of this minimum angle of deviation ($\delta_{min}$).

**Condition when δ will be minimum**

δ will be minimum when

$\angle i = \angle i'$ and $\angle r = \angle r'$

i.e., when angle of incidence equals to the angle of emergence.

$\delta_{min} = 2i - A$ or $i = \frac{1}{2}(A + \delta_{min})$

From (3)

$$\angle A = \angle r + \angle r' \Rightarrow A = 2r \therefore r = \frac{A}{2}$$

$$\text{Now, } \mu = \frac{\sin i}{\sin r} \Rightarrow \mu = \frac{\sin\left(\frac{A+\delta_{min}}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

## FOR A SMALL ANGLED PRISM

If A is small and measured in radians, then $\sin\left(\frac{A+\delta_{min}}{2}\right) \approx \frac{A+\delta_{min}}{2}$ and $\sin\left(\frac{A}{2}\right) \approx \frac{A}{2}$

Putting these values in above-derived formula, we get

$$\mu = \frac{\frac{A+\delta_{min}}{2}}{\frac{A}{2}} \quad \text{or} \quad \mu = \frac{A+\delta_{min}}{A}$$

$\mu A = A + \delta_{min} \therefore \delta_{min} = (\mu - 1) A$

It is generally written as below

$$\delta = (\mu - 1) A$$

## Knowledge ENHANCER

**1. Condition of no emergence of a ray from a prism :**

The light will not emerge out of a prism for all values of angle of incidence if at face $AB$, $i_1 = \max = 90°$,

at face $AC$, $r_2 > \theta_C$ ............... (1)

Now from Snell's law, at face $AB$, we have

$1 \times \sin 90° = \mu \sin r_1$

i.e., $r_1 = \sin^{-1}(1/\mu)$ or $r_1 = \theta_C$ ............... (2)

So from eq. (1) and (2), $r_1 + r_2 > 2\theta_C$ ............... (3)

However, in a prism, $r_1 + r_2 = A$ ............... (4)

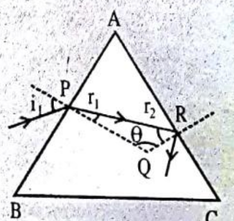



Fig. 2.10

So from eq. (3) and (4), $A > 2\theta_C$

or $\sin(A/2) > \sin\theta_C$ i.e., $\mu > [\text{cosec}(A/2)]$

i.e., A ray of light will not emerge out of a prism (whatever be the angle of incidence) if $A > 2\theta_C$, i.e., if $\mu > [\text{cosec}(A/2)]$

**2. Maximum deviation from a prism :**

Deviation will be maximum when angle of incidence $i_1$ is maximum, i.e., $i_1 = 90°$, so eq. reduces to :

$$\delta_{max} = 90° + i_2 - A$$

However, when $i_1 = 90°$, $1 \sin 90° = \mu \sin r_1$

i.e., $r_1 = \sin^{-1}(1/\mu)$ or $r_1 = \theta_C$

and as in a prism $(r_1 + r_2) = A$, $r_2 = (A - \theta_C)$

So at surface AC, $\mu \sin r_2 = 1 \sin i_2$ i.e., $\sin i_2 = \mu \sin(A - \theta_C)$

or $i_2 = \sin^{-1}[\mu \sin(A - \theta_C)]$

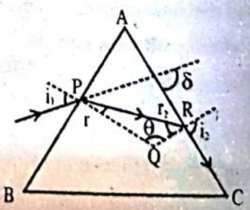



Fig. 2.11

## ILLUSTRATION - 2.3

A ray of light falls normally on a refracting face of a prism of the refractive index $\mu = 1.5$ of its material. Find the angle of prism, if the ray just fails to emerge from the prism.

**SOLUTION :**

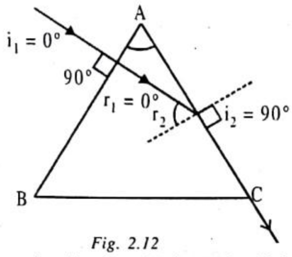



*Fig. 2.12*

The angle of incidence of the ray of light at the refracting face $AB$ is $i_1 = 0$ which implies that the angle of refraction at this face is $r_1 = 0$ and then,

$$r_1 + r_2 = A \Rightarrow r_2 = A$$

At the second refracting face $AC$, the ray just fails to emerge and therefore,

$r_2 = A = i_c$

$$A = \sin^{-1}\left(\frac{1}{\mu}\right) = \sin^{-1}\left(\frac{1}{1.5}\right) = \sin^{-1}\left(\frac{2}{3}\right) = 42°$$

## ILLUSTRATION - 2.4

An equilateral prism is having the refractive index $\mu = 1.5$ of its material. Calculate (i) the angle of incidence $i_1$ of a ray of light for the minimum deviation $\delta_m$ and (ii) the angle of emergence $i_2$ of the ray of light for the maximum deviation $\delta_{max}$.

**SOLUTION :**

For minimum deviation $\delta_m$, we have

(i) $$\mu = \frac{\sin\left(\frac{\delta_m + A}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

$$\Rightarrow \quad 1.5 = \frac{\sin\left(\frac{\delta_m + 60°}{2}\right)}{\sin\left(\frac{60°}{2}\right)} \Rightarrow \sin\left(\frac{\delta_m + 60°}{2}\right) = 0.75$$

$$\Rightarrow \quad \frac{\delta_m + 60°}{2} = 49° \Rightarrow \delta_m = 38°$$

$$\Rightarrow \quad 2i_1 - A = 38° \Rightarrow i_i = \frac{60° + 38°}{2} = 49°$$

(ii) For the maximum deviation $\delta_{max}$ of the ray light, we have

$i_1 = 90°$

$$r_1 = i_c = \sin^{-1}\left(\frac{1}{1.5}\right) = \sin^{-1}\frac{2}{3} = 42°$$

$\Rightarrow \quad r_2 = A - r_1 = 60° - 42° = 18°$

Then, by the *Snell's Law*, we have

$\sin i_2 = \mu \sin r_2$

$$= 1.5 \times \sin 18° = 1.5 \times 18 \times \frac{\pi}{180} = 0.465$$

$\Rightarrow \quad i_2 = 28°$

**ILLUSTRATION 2.5**

Find the angle of deviation suffered by a ray of light is passing through a thin prism, as shown. The refractive index of prism material is $\mu = 1.5$.

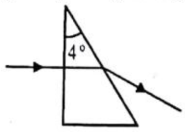



*Fig. 2.13*

**SOLUTION:**

The angle of deviation suffered by the ray of light in passing through the thin prism of angle $A = 4°$ will be

$$\delta = (\mu - 1)A = (1.5 - 1)4° = 2°$$

## DISPERSION OF WHITE LIGHT BY A GLASS PRISM

The refraction law underlies the phenomenon of the dispersion of light, that is the decomposition of the white light into the component colours when passing through a prism or through a transparent object delimited by non parallel surfaces. A beam of light containing all the visible spectrum of the light is white, because the sum of all the colors generates the white color. Normally the light we use is white. It's the light containing all the colors mixed together. We can realize this fact when the beam of light passes through a glass prism: the light is decomposed in all the component colours, Violet, Indigo, Blue, Green, Yellow, Orange and Red, called as VIBGYOR. The band of the coloured components of a light beam is called its spectrum.

The phenomenon can be explained by thinking that light of different colours (different wavelengths) has different velocities while travelling in a medium: $v_m = f\lambda_m$.

Hence, the change in velocity of light observed when the light passes from the air to the glass, depends on the wavelength.

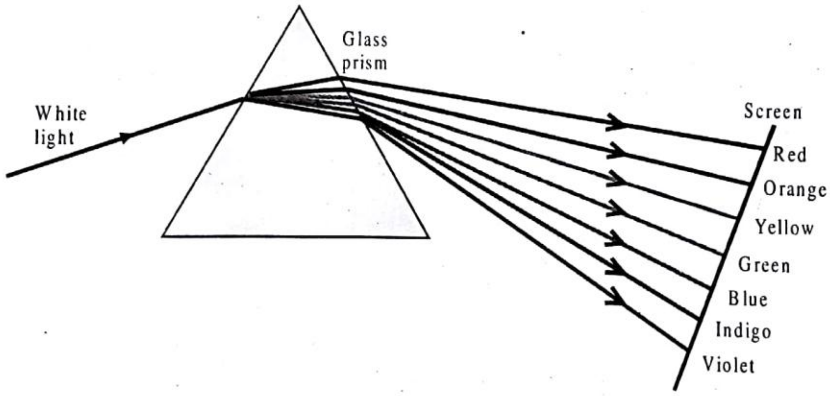



*Fig. 2.14*

By passing the interface air-glass, lower is the wavelength lower becomes the velocity of the light, so, for example, red light rays are faster than violet light rays.

This change in velocity coupled with the direction of the light beam to the air-glass interface explains the decomposition of a white light ray in the component colours while it is passing through a prism.

This phenomenon is known as "dispersion of light through a prism" and it is also responsible for rainbows during storms: as a matter of fact, each raindrop can be regarded as a little prism; when a light ray strikes a raindrop it is refracted and decomposed, spreading out all the visible colours ranging from red to violet.

## ANGLE OF DISPERSION

The angle between the rays of the extreme colours in the refracted (dispersed) light is called the angle of dispersion $\theta$.

That is, $\theta = \delta_V - \delta_R$

## DISPERSIVE POWER ($\omega$) :

Dispersive power of the medium of the material of prism is given by

$$\omega = \left(\frac{\text{angular dispersion}}{\text{deviation of mean ray (yellow)}}\right) = \frac{\theta}{\delta_Y}$$

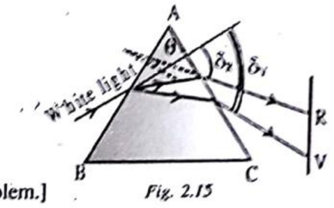



*Fig. 2.15*

For small angled prism ($A \le 10°$) with light incident at small angle $i$.

$$\omega = \frac{\delta_V - \delta_R}{\delta_Y} = \frac{\mu_V - \mu_R}{\mu_Y - 1}$$ [take $\mu_Y = \frac{\mu_V + \mu_R}{2}$ if value of $\mu_Y$ is not given in the problem.]

$\mu_V$, $\mu_R$ and $\mu_Y$ are R.I. of material for violet, red and yellow colours respectively.

## CAUSE OF DISPERSION

The cause of dispersion is the dependence of the refractive index ($\mu$) on wavelength of light which is given by Cauchy's formula

$$\mu(\lambda) = a + \frac{b}{\lambda^2}$$ (where $a$ and $b$ are positive constants)

The different colours of light corresponds of different refractive index of the prism. Hence, different colours have different velocities in the prism and hence get separated from one another.

**Combination of Two Prisms**

If two prisms of prism angles $A$ and $A'$ and refractive indices $\mu$ and $\mu'$ are placed together,

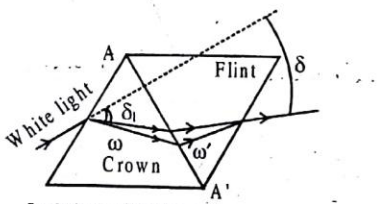
$$\delta = \delta_1 + \delta_2 = (\mu - 1)A + (\mu' - 1)A'$$

and $\theta = \theta_1 + \theta_2 = (\mu_V - \mu_R)A + (\mu'_V - \mu'_R)A'$

**(a) For deviation without dispersion (Achromatic Prism)**

$$\theta = 0, \quad i.e., \quad A' = -\frac{(\mu_V - \mu_R)}{(\mu'_V - \mu'_R)}A \quad \text{............(1)}$$

i.e., the two prisms must be placed with their prism angles in opposite directions so that condition given by eq. (1) may be satisfied. In this situation




*Deviation without dispersion*

*Fig. 2.16 (a)*

$$\delta = (\mu - 1)A - (\mu' - 1)\frac{(\mu_V - \mu_R)}{(\mu'_V - \mu'_R)}A \qquad \text{i.e.,} \qquad \delta = (\mu - 1)A\left[1 - \frac{(\mu_V - \mu_R)}{(\mu - 1)} \times \frac{(\mu' - 1)}{(\mu'_V - \mu'_R)}\right]$$

But as $\delta_1 = (\mu - 1)A$, $\omega = \frac{(\mu_V - \mu_R)}{(\mu - 1)}$ and $\omega' = \frac{(\mu'_V - \mu'_R)}{(\mu' - 1)}$

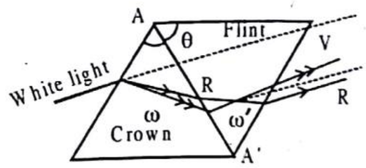
$$\delta = \delta_1[1 - (\omega/\omega')] \quad \text{............(2)}$$

Usually $\omega' > \omega$, so $\delta$ is in the same direction as produced by the first prism.

**(b) For dispersion without deviation (Direct vision prism)**

$$\delta = 0 \quad \text{i.e.,} \quad A' = -\frac{(\mu - 1)}{(\mu' - 1)} A$$

In this situation, $\theta = (\mu_V - \mu_R)A - (\mu'_V - \mu'_R) \times \frac{(\mu - 1)}{(\mu' - 1)} A$




*Dispersion without deviation*
*Fig. 2.16 (b)*

i.e., $\theta = (\mu - 1) A \left[ \frac{(\mu_V - \mu_R)}{(\mu - 1)} - \frac{(\mu'_V - \mu'_R)}{(\mu' - 1)} \right]$ or $\theta = \delta[\omega - \omega']$

If $\omega' > \omega$, the resultant dispersion is negative, i.e., opposite to that produced by the first prism.

**ILLUSTRATION 2.6**

White light passes through a thin prism of angle 6°. If the refractive indices for the red and violet colours are 1.641 and 1.659, respectively, what is the angular dispersion produced by the prism?

**SOLUTION:**

The angular dispersion produced by the prism is

$$\theta = (\mu_V - \mu_R)A$$
$$= (1.659 - 1.641)6°$$
$$= 0.018 \times 6° = 0.108°$$

**ILLUSTRATION 2.7**

In the previous Illustration, calculate the dispersive power of prism material.

**SOLUTION:**

$$\mu_y = \frac{\mu_V + \mu_R}{2} = \frac{1.659 + 1.641}{2} = 1.65$$

Then, $$\omega = \frac{(\mu_V - \mu_R)}{(\mu_y - 1)} = \frac{(1.659 - 1.641)}{(1.650 - 1)} = \frac{0.018}{0.650} = 0.0277$$

**ILLUSTRATION 2.8**

The crown glass has the refractive indices 1.51 and 1.49 for the blue and red lights, respectively, and the flint glass has the refractive indices 1.77 and 1.73 for the blue and red lights, respectively. A beam of white light is incident on a combination of two thin isosceles prisms, one of crown glass of angle $A = 6°$ and other of flint glass of unknown angle $A'$. If there is no net deviation of the light in passing through the combination, calculate the angle A′ and the net angular dispersion produced by the combination.

**SOLUTION:**

The net deviation of light produced by the combination of two prisms is zero and therefore,

$$(\mu_y - 1)A + (\mu_y - 1)A' = 0$$

$$\Rightarrow \quad A' = -\frac{(\mu_y - 1)A}{(\mu_y' - 1)} = -\frac{[(\mu_V + \mu_R)/2 - 1]A}{[(\mu_V' + \mu_R')/2 - 1]} = -\frac{(\mu_V + \mu_R - 2)A}{(\mu_V' + \mu_R' - 2)} = -\frac{(1.51 + 1.49 - 2)6°}{(1.77 + 1.73 - 2)} = 4°$$

where the minus sign indicates that the second prism of flint glass of angle A′ = 4° is placed inverted with respect to the first prism of crown glass of angle A = 6°.

Then the net angular dispersion of light produced by the combination is

$$\theta = (\mu_V' - \mu_R')A' + (\mu_V - \mu_R)A$$
$$= -(1.77 - 1.73)4° + (1.51 - 1.49)6° = -0.04 \times 4° + 0.02 \times 6 = -0.04$$

## TOTAL INTERNAL REFLECTION (TIR):

**THE PHENOMENON :** In case of refraction of light, from snell's law we have

$\mu_1 \sin i = \mu_2 \sin r$ ........(1)

If light is passing from denser to rarer medium through a plane boundary then $\mu_1 = \mu_D$ and $\mu_2 = \mu_R$ so

$$\sin i = \frac{\mu_R}{\mu_D} \sin r \text{ i.e. } \sin i = \frac{\sin r}{\mu} \text{ with } \mu = (\mu_D/\mu_R) \quad .......(2)$$

i.e., $\sin i \propto \sin r$ with $(\angle i) < (\angle r)$ (as $\mu > 1$)

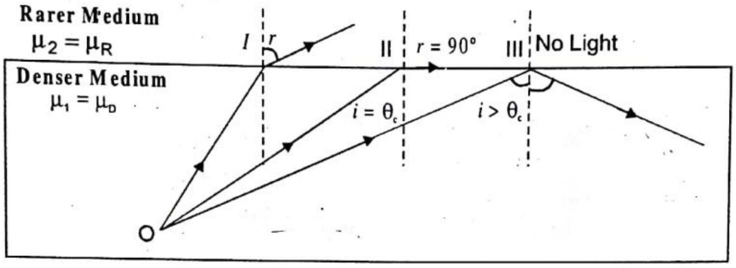



*Fig. 2.17*

So, as angle of incidence $i$ increases, angle of refraction $r$ will also increase and for certain value of $i$ ($\angle 90°$), $r$ will become 90°. The value of angle of incidence for which $r = 90°$ is called critical angle and is denoted by $\theta_c$. From eq. (2)

$$\sin \theta_C = \frac{\sin 90°}{\mu} \text{ i.e., } \quad \sin \theta_C = \frac{1}{\mu} \quad ..........(3)$$

And hence eqn. (2) in terms of critical angle can be written as

$$\sin i = \sin r \times \sin \theta_c \text{ i.e., } \quad \sin r = \frac{\sin i}{\sin \theta_C} \quad ...........(4)$$

So, if $i > \theta_c$, $\sin r > 1$. This means that $r$ is imaginary (as the value of sin of any angle can never be greater than unit) physically this situation implies that refracted ray does not exist. So, the total light incident on the boundary will be reflected back into the same medium from the boundary. This phenomenon is called total internal reflection.

For total internal reflection to take place light should pass from a denser medium to a rarer medium. It light passes from air to water (or glass) or from water to glass, total internal reflection can-never take place.

When light is passing from denser to rarer medium, total internal reflection will take place only if angle of incidence is greater than a certain value called critical angle given by : $\theta_C = \sin^{-1}\left[\frac{1}{\mu}\right]$ with $\mu = \frac{\mu_D}{\mu_R}$

In case of total internal reflection, as all (i.e. 100%) incident light is reflected back into the same medium there is no loss of intensity while in case of reflection from mirror or refraction from lenses, there is some loss of intensity as all light can never be reflected or refracted. This is why image formed by TIR are much brighter than formed by mirror or lenses.

## CRITICAL ANGLE ($\theta_c$)

In case of propagation of light from denser of rarer medium through a plane boundary, critical angle is the angle of incidence for which angle of refraction is 90° and so from snell's law

$\mu_1 \sin i = \mu_2 \sin r$

$$\mu_D \sin\theta_C = \mu_R \sin 90$$

i.e. $$\sin \theta_C = \frac{\mu_R}{\mu_D} = \left[\frac{1}{\mu}\right] \text{ with } \mu = \frac{\mu_D}{\mu_R} \text{ or } \theta_C = \sin^{-1}\left(\frac{1}{\mu}\right)$$

For a given pair of medium critical angle depends on wavelength of light used i.e., greater the wavelength of light lesser will be $\mu \left[\text{as } \mu \propto \frac{1}{v} \propto \frac{1}{\lambda}\right]$ and so greater will be the critical angle. This is why critical angle is maximum for red and minimum for violet rays.

For a given light $\theta_c$ depends on the nature of the pair of medium, lesser the $\mu$ greater will be the critical angle and vice–versa.

This is why in case of

| Glass air | Water air | Glass Water |
|---|---|---|
| As $\mu_g = \frac{3}{2}$ and $\mu_A = 1$ | As $\mu_w = \frac{4}{3}$ and $\mu_A = 1$ | As $\mu_G = \frac{3}{2}$ and $\mu_w = \frac{4}{3}$ |

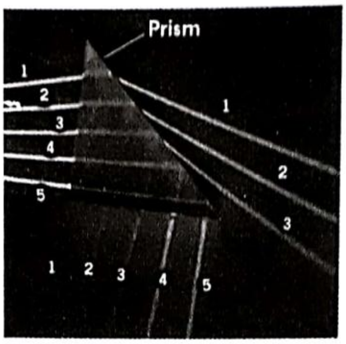



*Fig. 2.18 : All rays reflect internally, but the top three rays reflect only a small percentage internally; most energy leaves the prism. The fourth and fifth rays are reflected 100% internally.*

| | | |
|---|---|---|
| i.e., $\mu = \frac{\mu_G}{\mu_A} = \frac{3}{2}$ | i.e., $\mu = \frac{\mu_W}{\mu_A} = \frac{4}{3}$ | i.e., $\mu = \frac{\mu_G}{\mu_W} = \frac{9}{8}$ |
| So $(\theta_C)_{GA} = \sin^{-1}\left[\frac{2}{3}\right] = 42°$ | so $(\theta_C)_{WA} = \sin^{-1}\left[\frac{3}{4}\right] = 49°$ | $(\theta_C)_{GW} = \sin^{-1}\left(\frac{8}{9}\right) = 63°$ |

## FISH LOOKING UP THROUGH WATER

It is interesting to see that to a fish at a depth $h$ inside water, the whole world outside appears to be within a circle of radius $R$, drawn in the water surface. The rays coming from the different objects of the world, are refracted at the water surface within the circle and form a cave with it's vertex at the eye of fish, as shown.

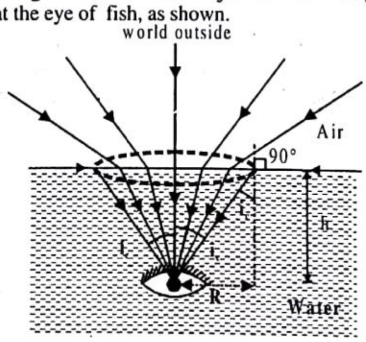



*Fig. 2.19*

From the geometry of figure, we have

$$R = h \tan i_c$$

$$= h\frac{\sin i_c}{\sqrt{1-\sin^2 i_c}} = \frac{h}{\sqrt{\frac{1}{\sin^2 i_c}-1}} = \frac{h}{\sqrt{\mu^2-1}} \Rightarrow R \propto h$$

where $\sin i_c = 1/\mu$ defines the critical angle for water. The angle of vertex of the cone is $2i_c$.

In another situation, if a source of light is placed at the position of eye of fish, those rays of light from the source which are incident on the water surface outside the circle at an angle $i > i_c$, are totally reflected back and cannot pass out of the surface but all those rays of light which are incident on the water surface within the circle at an angle $i$ = or < $i_c$, pass out of surface. Thus, an illuminated circular path of the radius $R$ is observed in the water surface.

## APPLICATIONS OF TIR

1. **Sparkling of diamond:** A diamond sparkles because, when it is held in a certain way, the intensity of the light coming from it is greatly enhanced. Fig. helps to explain that this enhancement is related to total internal reflection. Part of the drawing shows a ray of light striking a bottom face of the diamond at an angle of incidence exceeding the critical angle, the ray is totally reflected back into the diamond, eventually exiting the top surface to give the diamond its sparkle. The critical angle is 24.4°. The value is so small, there fore the index of refraction of diamond is large compared to that of air.
   Now consider what happens to the same ray of light within the diamond when the diamond is placed in water. Because water has a larger index of refraction than air, the critical angle increases to 33.3°. Therefore, this only part of the light is reflected back into the diamond, and the remainder escapes into the water. Consequently, less light exits from the top of the diamond, causing it to lose much of its brilliance.

*Fig. 2.20 (a)*

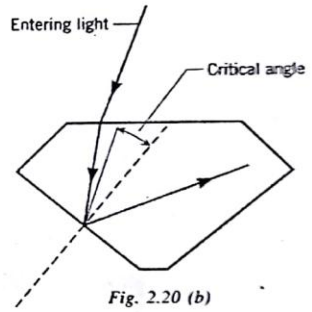



*Fig. 2.20 (b)*

2. **Optical fibre**
   Take a thin solid wire (called strand) made up of glass or quartz, etc. Coat it from outside with some material whose μ is less than that of glass or quartz, etc. Now, because it is thin, hence whichever ray of light enters it from one of its ends, will strike the inside surface at some angle which will definitely be greater than the critical angle. Hence, it will suffer total internal reflection again and again until it comes out from the other end. This is the principle on which optical fibres work.
   Hence, in effect, light can travel axially within an optical fibre, although the axis of fibre may be flexible having bent or wavy profile.
   A bundle of optical fibres is called a light pipe and is able to send image of an extended object from one end to another by picking up images of small-small parts of the object and sending them likewise to the other end.

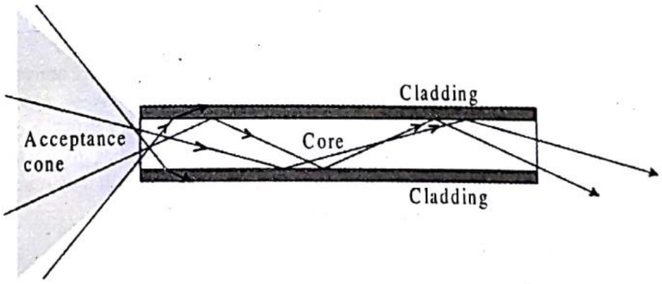



*Fig. 2.21(a) : Optical fibre showing total internal reflection of light.*

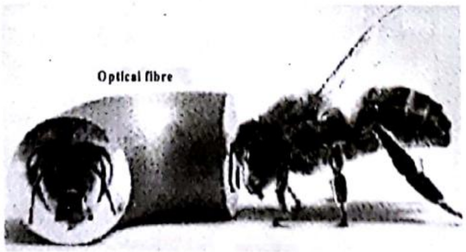



*Fig. 2.21(b) : Optical fibre sending an image of an extended object from one place to other.*

**Use of Optical fibres**

(a) For medical examination inside the stomach, intestines etc., called endoscopy.

*Fig. 2.22*

(b) The recent trend is to send even electrical signals through optical fibres, by converting them into electromagnetic radiations/light waves.

**3. Duration of Sun's Visibility**

In presence of atmosphere (in which μ decreases with height) due to the phenomenon of TIR, the sun will become visible even when it is below the horizon (when $i > \theta_C$) and will remain visible for some time even when it goes below the horizon. This results in increase in duration for which the sun is Cvisible. It is estimated that due to this effect the period of visibility of the sun increases by 2 minutes in the morning and 2 minutes in the evening.

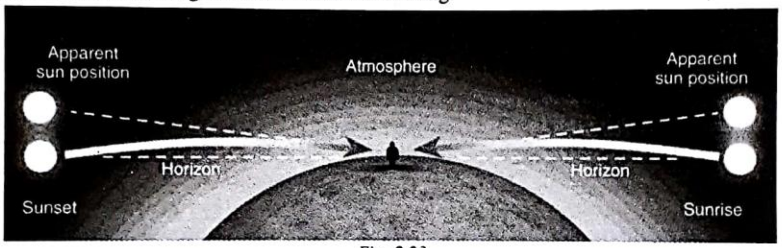



*Fig. 2.23*

**4. Mirage**

It is an optical illusion, in which inverted image of a distant object can be seen, as it reflected from a pond or a lake in hot regions due to continuous atmospheric refraction and total internal reflection.

In deserts, because of intense heat, the layers of air, near the surface of the earth, get heated so soon that the density adjusment does not take place, hence the densities and refractive indices of the layers immediately above the sand are lower than those of the layers higher up. The rays of light from a distant object, after passing through layers, which are gradually less refracting, bend more and more away from normal, till they fall on a layer at an angle, greater than the critical angle and it gets totally reflected. These reflected rays then travel up and undergo a series of refractions, but in a direction opposite to those in first case, they now pass through layers which are gradually more and more refracting, till they reach the eye of the observer, who sees an image of the object, as though reflected from the surface of a lake of water.

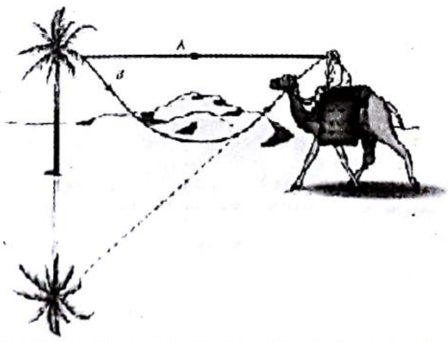


*Fig 2.24(a) Hot air near desert has a lower index of refraction than the cooler air above.*

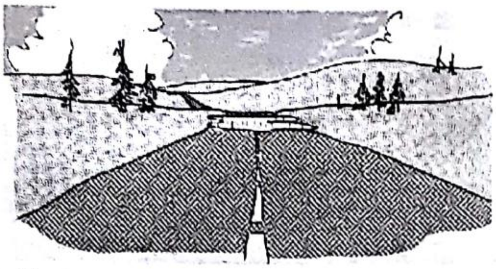


Fig. 2.24 (b) : There's no water on the road; but it appears so due to total internal reflection.

5. **Looming**

It is an optical illusion in which inverted image of a distant object can be seen, as if reflected from a pond or lake or sometimes, as if suspended in the atmosphere in cold regions due to continuous atmospheric refraction and total internal reflection.

In cold region, air above water is cold (denser) whereas above it, it is hot (rarer). So, when light ray from the object travels from cold to warm air (denser to rarer) it undergoes continuous atmospheric refraction, and causes total internal reflections in downward directions due to which we see objects hanging up in sky.

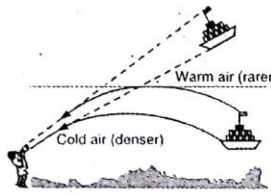



Fig. 2.25 : Looming observed in very cold region is caused by the total internal reflection of light coming from the ship (or any other object)

## CHECK Point

- **Rays of light in water that shine up to the water-air boundary at angles of more than 48° to the normal are totally reflected. No rays beyond 48° refract outside. How about the other way around? Is there an angle at which light rays in air meeting the air-water boundary will reflect totally? Or will some light be refracted at all angles?**

### SOLUTION

Total internal reflection only takes place when light goes from denser to rarer medium as from water to air. It cannot take place other way around, like the case in which light rays in air meets air-water boundary. Light rays coming from air and incident on water surface will always be refracted. There is not any angle at which light rays in air meeting air-water boundary will be reflected totally. Some light will be refracted at all angles except when the ray of light grazes the air-water interface.

## ILLUSTRATION 2.9

A light ray falls on a square glass slab at an angle of incidence 45°, as shown. What must be the refractive index of glass, if the total internal refraction occurs at the vertical face?

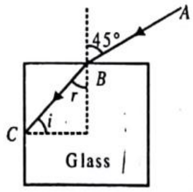



Fig. 2.26

**SOLUTION:**

If the light ray is to undergo the total internal reflection at the point $C$ of a vertical face of the glass slab, the angle of incidence $i$ must be greater than the critical angle $i_c$ for glass. Taking $i = i_c$,

$$\sin i = \sin i_c = \frac{1}{\mu}$$

$$\Rightarrow \quad \cos i = \sqrt{1-\sin^2 i} = \sqrt{1-\frac{1}{\mu^2}}$$

and then, by the *Snell's law,*

$$\sin r = \frac{\sin 45°}{\mu} = \frac{1}{\sqrt{2}\mu}$$

Equating cos $i$ and sin $r$, we have

$$\Rightarrow \quad \cos i = \sin r$$

$$\Rightarrow \quad \sqrt{1-\frac{1}{\mu^2}} = \frac{1}{\sqrt{2}\mu} \qquad \Rightarrow \quad \mu = \sqrt{3/2} = 1.22$$

which is the minimum refractive index of glass for the total internal reflection to occur at the point $C$.

**ILLUSTRATION 2.10**

A point source $S$ of light is placed at the bottom of a vessel, containing a liquid of refractive index $\mu = 5/3$. A person is viewing the source $S$ from above the surface of liquid. There is an opaque disc of diameter 2 cm, floating on the liquid surface. The centre of disc lies vertically above the source $S$. When the liquid is gradually drained out through a tap, what is the maximum height $h$ so that the source cannot at all be seen?

**SOLUTION:**

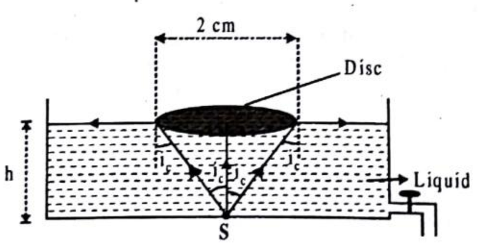



*Fig. 2.27*

When the height of liquid above the point source $S$ of light placed at the bottom of vessel is $h$, then an illuminated circular patch of radius $R$ is seen in the liquid surface exactly above the source.

$$R = \frac{h}{\sqrt{\mu^2 - 1}} \Rightarrow R \propto h$$

If $R$ = 1cm, the corresponding value of $h$ is given by

$$h = R\sqrt{\mu^2 - 1}$$

$$= 1\text{ cm} \times \sqrt{(5/3)^2 - 1} = 1.33\text{ cm}$$

which gives the maximum value of $h$ so that the illuminated circular patch of 1 cm radius becomes invisible, i.e., the source $S$ is not seen at all from above, when the opaque disc of 1 cm radius is put on the circular patch.

## RAINBOW

You must have observed most spectacular light shown on earth i.e., rainbow. Indeed the traditional rainbow is sunlight spread out into its spectrum of colours and diverted to the eye of the observer by water droplets. The "bow" part of the word describes the fact that the rainbow is a group of nearly circular arcs of color all having a common center.

Rainbows are generated through refraction and reflection of light in small rain drops. The sun is always behind you when you face a rainbow, and that the center of the circular arc of the rainbow is in the direction opposite to that of the sun. The rain, of course, is in the direction of the rainbow i.e., rain drops must be ahead of you and the angle between your line-of-sight and the sunlight will be 40°–42°.

Fig. 2.28

After rain, there are still some tiny water droplets remained in the air. If there is sunshine, a white sunbeam will be reflected and refracted by these tiny droplets. Different colors of light have different refractivity. They will be reflected in slightly in different directions inside a water droplet. Since, water is more dense than air, light is refracted as it enters the drop-red is bent less, blue more. Some of the light will reflect off the back of the drop if the angle is larger than the critical angle (48° for water)

The light is then refracted again as it leaves the drop (act like a small prism), the colours of white light have been dispersed.

- violet light will leave the drop at an angle of 40° from the beam of sunlight
- red light will leave the drop at an angle of 42° from the beam of sunlight.

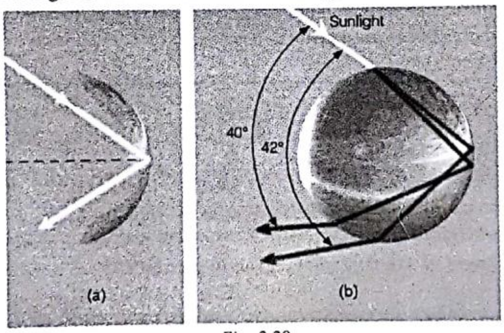



Fig. 2.29

However, you can not see the blue light and red light refracted from the same drop.
So, many drops are involved in producing the rainbow
you can only see one wavelength of light refracted from one drop.
So, to see a rainbow, you need to see light refracted from many drops.
Hence, red will be on the top and blue will be on the bottom of the rainbow.

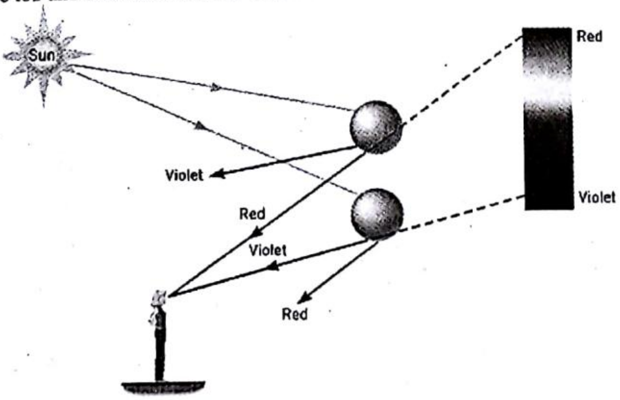



Fig. 2.30 : Forming a Rainbow.

Both the primary and secondary rainbows are phenomena that are formed by the reflection and refraction of sunlight in tiny water droplets. When a sunbeam is being refracted twice and reflected once by the droplet, a primary rainbow will form. If the beam is being refracted twice and reflected twice, a secondary rainbow will form. As the secondary rainbow is formed by one more reflection than the primary rainbow, it is much fainter and rare to see. On the other hand, since the paths of sunbeams in a primary rainbow and a secondary rainbow are different, the colours of the secondary rainbow are arranged in just the reverse order of the primary one.


*(a) Formation of primary rainbow* *(b) Formation of secondary rainbow*

*Fig. 2.31*

**CHECK Point**

- **A rainbow viewed from an airplane may form a complete circle. Where will the shadow of the air-plane appear ? Explain**

**SOLUTION**

A rainbow viewed from an airplane may form a complete circle because the earth doesnot come in the way of the airplane and rainbow and as a rainbow is a three dimensional cone of dispersed light it will appear as a complete circle. The shadow of the airplane will appear with in the circle of the rainbow.

## ATMOSPHERIC REFRACTION

### Twinkling of stars

The scientific name for the twinkling of stars is stellar scintillation (or astronomical scintillation). Stars twinkle when we see them from the Earth's surface because we are viewing them through thick layers of turbulent (moving) air in the Earth's atmosphere.

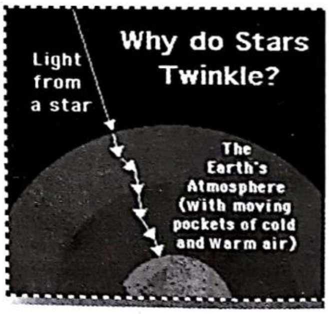



*Fig. 2.32*

Stars (except for the Sun) appear as tiny dots in the sky; as their light travels through the many layers of the Earth's atmosphere, the light of the star is bent (refracted) many times and in random directions (light is bent when it hits a change in density-like a pocket of cold air or hot air). This random refraction results in the star winking out (it looks as though the star moves a bit, and our eye interprets this as twinkling).

Stars closer to the horizon appear to twinkle more than stars that are overhead - this is because the light of stars near the horizon has to travel through more air than the light of stars overhead and so is subject to more refraction.

Also, planets do not usually twinkle, because they are so close to us; they appear big enough that the twinkling is not noticeable (except when the air is extremely turbulent).

Stars would not appear to twinkle if we viewed them from outer space (or from a planet/moon that didn't have an atmosphere.

Since the atmosphere bends starlight towards the normal, the apparent position of the star is slightly different from its actual position. The star appears slightly higher (above) than its actual position when viewed near the horizon. Further, this apparent position of the star is not stationary, but keeps on changing slightly, since the physical conditions of the earth's atmosphere are not stationary.

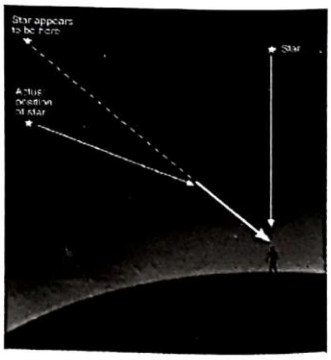


*Fig. 2.33*

## SCATTERING OF LIGHT

The interplay of light with objects around us gives rise to several spectacular phenomena in nature. The blue colour of the sky, colour of water in deep sea, the reddening of the sun at sunrise and the sunset are some of the wonderful phenomena we are familiar with all this is because of scattering of light.

When sunlight enters the earth atmosphere, air and water vapour molecules will absorb part of the light and reradiate it to all directions. This is called scattering. Generally two types of scattering are consider mie and rayleigh.

**Mie Scattering**

- large particles in the atmosphere are able to scatter all wavelengths of white light equally
- when all wavelengths of white light are scattered equally, then Mie scattering is occurring
- this is why clouds appear white.

**Rayleigh scattering.** The selective scattering of the shorter wavelengths of visible light (violet and blue) by atmospheric gases. Note that Rayleigh scattering involves much smaller scattering particles than Mie scattering

**Orange/red sunsets in a clean atmosphere :**

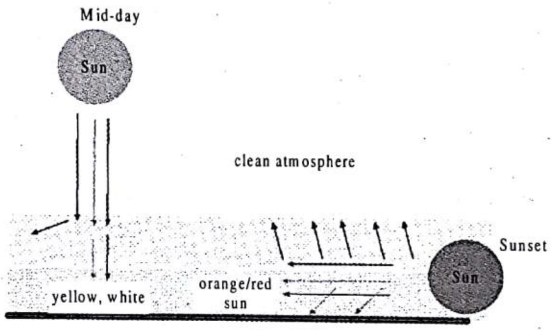



*Fig. 2.34*

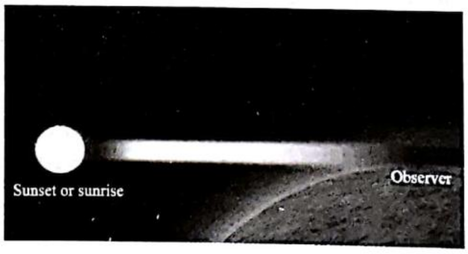



*Fig. 2.35*

At mid-day, only a bit of the short wavelengths of visible light are scattered since the radiation is passing through a small distance in the atmosphere.

At sunset, however, the radiation must pass through a much thicker layer of the atmosphere.

When the sun is at an angle of 4° from horizontal, the atmosphere appears to be 12 times thicker than at mid-day.

Hence, much more blue light, and some green light are scattered.

Therefore, the sun appears to look orange/red.

**Orange/red sunsets in a dirty atmosphere :**

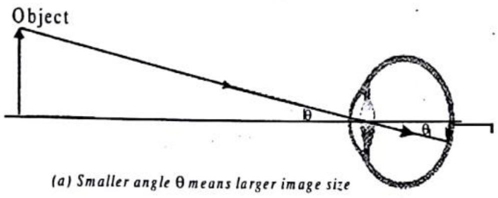
When pollution is present, the atmosphere contains more particles such as aerosols having larger diameters than the atmospheric gases. Hence, more of the intermediate wavelengths of visible light such as yellow and green are scattered in addition to the blue light what largely remains is red light, hence the sun appears red.

## OPTICAL INSTRUMENTS

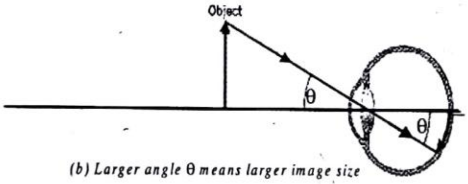
The size of the image on the retina determines how large an object appears to be. However, the size of the image on the retina is difficult to measure. Alternatively, the angle $\theta$ subtended by the image can be used as an indication of the image size. Figure shows this alternative, which has the advantage that $\theta$ is also the angle subtended by the object and, hence, can be measured easily. The angle $\theta$ is called the angular size of both the image and the object. The larger the angular size, the larger the image on the retina, and the larger the object appears to be.

Angular magnification (X) = visual angle when object is placed at least distance of distinct vision

**Visual angle with instrument**




*(a) Smaller angle θ means larger image size*




*(b) Larger angle θ means larger image size*

*Fig. 2.36 : In both (a) and (b) the objects have the same size, but in (b) the image on the retina is larger because the object is closer to the eye. The angle θ is the angular size of both the image and the object.*

## SIMPLE MICROSCOPE (MAGNIFYING GLASS OR READING LENS)

It is also known as magnifying glass or simply magnifier and consists of a convergent lens with object between its focus and optical centre and eye close to it. The image formed by it is erect, virtual enlarged and on same side of lens between object and infinity.

**Magnification by a simple microscope**

The magnifying power (MP) or angular magnification of a simple microscope (or an optical instrument) is defined as the ratio of visual angle with instrument to the maximum visual angle for clear vision when eye is unadded (i.e., when the object is at least distance of distinct vision)

$$\text{i.e., MP} = \frac{\text{Visual angle with instrument}}{\text{Max. visual angle for unadded eye}} = \frac{\theta}{\theta_0}$$

**Case 1: Eye focussed at near point i.e., the image is formed at a distance *D* from the lens/eye**

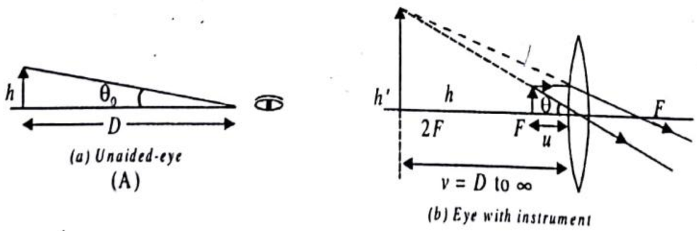



*Fig. 2.37*

In this case, $v = D$

$$M = \frac{v}{u} = v \times \frac{1}{u} = v \times \left(-\frac{1}{f} + \frac{1}{v}\right)$$

Now, according to our sign convention $v$ is equal to $(-D)$ here.

$$\therefore\ M = (-D) \times \left(-\frac{1}{f} + \frac{1}{-D}\right) \quad \text{or} \quad M = 1 + \frac{D}{f} \quad \text{........... (A)}$$

**Case 2: Eye focussed at infinity (Normal adjustment)**

In this case, we find out angular magnification. If the object is viewed directly by the eye, keeping the object at the near point, then

$$\theta_0 = \frac{O}{D} \quad \text{............ (1)}$$

Now, let us find the angle subtended by its image, if the image is formed at $\infty$. In this case, the object will have to be kept at the focus of the lens.

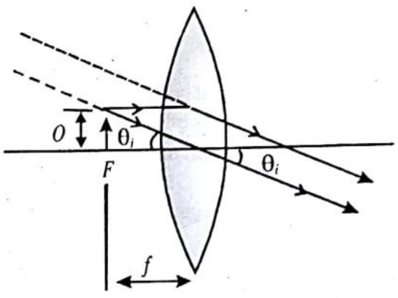


*Fig. 2.38*

In this case, $\theta_i = \dfrac{O}{f}$ $\therefore$ $M = \dfrac{\theta_i}{\theta_0} = \dfrac{O/f}{O/D}$ or $M = \dfrac{D}{f}$ ............ (B)

This is one less than the magnification when the image is formed at the near point, but, naturally, viewing is more comfortable and the difference in magnification usually small.

For example, if we want a magnification of six, $f$ required will be 5 cm in the first case (taking D = 25 cm) and (D/6 = 25/6) $\approx$ 4 cm is the second case.

For all practical purposes, it is not possible to have magnification > 10 through a simple microscope.

## USES

The watch makers use of convex lens to have a magnified view of the small parts of the watch. The magnified glass is also used to see slides. It is also used in laboratories to note vernier readings.

## CHECK Point

- **The angle subtended at the eye by an object is equal to the angle subtended at the eye by the virtual image produced by a magnifying glass. In what sense then does a magnifying glass provide angular magnification?**

**SOLUTION**

In magnifying glass the object is placed closer than 25 cm, which produce image at 25 cm. This closer object has larger angular size than the same object at 25 cm. In this way although the angle subtended by virtual image and object is same at eye but angular magnification is achieved.

## COMPOUND MICROSCOPE

**Construction:** It consists of two convergent lenses of short focal lengths and apertures arranged co-axially. Lens (of focal length $f_0$) facing the object is called objective or field lens while the lens (of focal length $f_e$) facing the eye, eye-piece or ocular. The objective has a smaller aperture and smaller focal length than eye-piece the separation between objective and eye-piece can be varied.

**Magnification of a compound microscope**

$M_0$, linear magnification due to the objective

$$= \frac{I_1}{O} = \frac{A_1B_1}{AB} \quad \text{or} \quad \frac{A_1B_1}{PQ} \quad \text{........... (1)}$$

Now $\Delta s$ $PQF_1$ and $B_1A_1F_1$ are similar,

$$\therefore\ \frac{A_1B_1}{B_1F_1} = \frac{PQ}{PF_1}$$

$$\text{or} \quad \frac{A_1B_1}{PQ} = \frac{B_1F_1}{PF_1} = \frac{L}{f_0} \quad \text{........... (2)}$$

Put (2) in (1) to get $M_0 = \dfrac{L}{f_0}$ ........... (3)

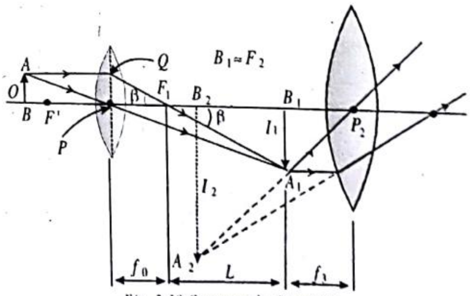


*Fig. 2.39 Compound microscope*

**Now, let the eye is focussed at $\infty$.** This means $A_1B_1$ (the image by objective) is made at the focus of the eyepiece. Angular magnification by eyepiece (i.e., a simple microscope, as already dealt with), $M_e$ will thus be

$$M_e = \frac{D}{f_e} \qquad \text{.......... (4)}$$

$\therefore$ Total magnification, $\quad M = M_0 \times M_e \quad$ or $\quad M = \frac{L}{f_0} \times \frac{D}{f_e}$

where, for all practical purposes $L$ is approximately equal to the length of the compound microscope, and $D = 25$ cm, and $f_0$ and $f_e$ are the focal lengths of the objective and eyepiece respectively.

**If the eye is focussed at near point,** $M_e$ will be (as already derived in case of a simple microscope) = $(1 + D/f_e)$.

Therefore the total magnification will become, $\quad M = \frac{L}{f_0} \times \left(1 + \frac{D}{f_e}\right)$

## CHECK Point

- **When viewing through a compound microscope, our eyes should be positioned not on the eyepiece but a short distance away from it for best viewing. Why ? How much should be that short distance between the eye and eyepiece?**

**SOLUTION**

If we place our eye too close to the eyepiece, we shall not collect much of the light and also reduce our field of view. When we position our eye slightly away and area at the pupil of our eye is greater,

Now our eye collects all the light refracted by the objective, and a clear image is observed by the eye.

## TELESCOPE

Telescope is used to provide angular magnification of distant objects. It is of many types, general categories are :

(i) Refracting type (lenses are used) (ii) Reflecting type (mirrors are used)

(iii) Astronomical, to view celestial objects (iv) Terrestial, to view objects on earth.

Thus, prism binoculars are also terrestial telescopes.

A refracting type astronomical telescope, used to see the distant objects at larg distances, consists of objective, i.e., a converging lens, or lens combination of larger focal length $f_0$ and larger aperture, and an eyepiece, i.e., also a converging lens, or lens combination, but of smaller focal length $f_e$ and smaller aperture, placed coaxially.

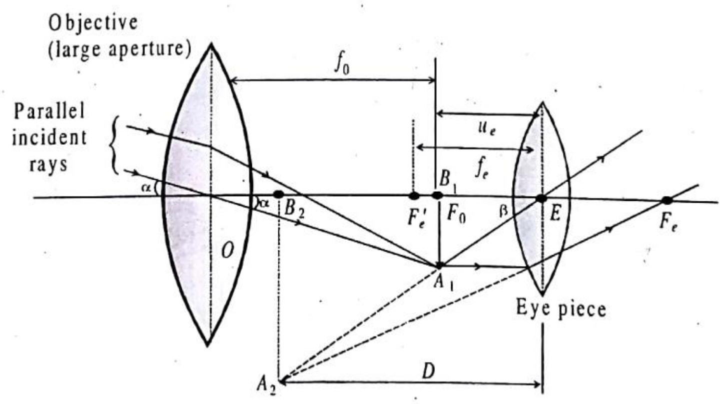



Fig. 2.40

**Magnifying power (M)**

Magnifying power ($M$), also called angular magnification of a telescope is defined as the ratio of the visual angle subtended by the final image at the eye and the visual angle subtended by the object when the object lies in the actual position. (In contrast to the definition of magnifying power of a microscope, the object is not placed at the near point in case of telescope. Why ?)

$$M = \frac{\beta}{\alpha} = \frac{\tan\beta}{\tan\alpha} \quad (\because \alpha, \beta \text{ are small})$$

$$M = \frac{A_1B_1 / EB_1}{A_1B_1 / OB_1} \quad (\text{in } \Delta AB_1O \text{ and } \Delta\ AB_1E) \Rightarrow \quad M = \frac{OB_1}{EB_1}$$

Using sign convention and taking $u_e$ as object distance for eyepiece, we get

$$M = \frac{+f_0}{-u_e} = -\frac{f_0}{u_e} \quad \text{............ (1)}$$

This is the general formula for magnifying power of a telescope.

**M, if eye is focussed at near point**

For the eyepiece, $v = -D, v = -u_e, f = +f_e$ where, $D$ = minimum distance of distinct vision

Using lens formula, we get $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$ , $\frac{1}{-D} - \frac{1}{-u_e} = \frac{1}{f_e}$

$$\therefore \quad \frac{1}{u_e} = \frac{1}{f_e} + \frac{1}{D} = \frac{1}{f_e}\left(1 + \frac{f_e}{D}\right) \quad \text{............ (2)}$$

Put (2) in (1), we get $M = -\frac{f_0}{f_e}\left(1 + \frac{f_e}{D}\right)$ ............ (3)

In this case, the length of the telescope is $= f_0 + u_e$.

**M when eye is focussed at $\infty$ (normal adjustment)**

In this case, as already explained, we have $u_e = -f_e$ ............ (4)

Put (4) in (1) to get $M = \frac{f_0}{f_e}$ ............ (5)

In this case, the length of the telescope $= f_0 + f_e$.

This is the reason why the focal length of objective is taken large and of eyepiece small in case of a telescope. This also increases the resolving power of the telescope.

Further, linear or lateral magnification does not convey much meaning in case of a telescope because the size of final images too is negligible compared to actual size of the objects which are generally planets or stars.

**Difference between Compound Microscope and Astronomical Telescope**

| Compound Microscope | Astronomical Telescope |
|---|---|
| 1. It is used to increase visual angle of near tiny object. | 1. It is used to increase visual angle of distant large objects. |
| 2. In it field and eye lens both are convergent, of short focal length and aperture. | 2. In it objective lens is of large focal length and aperture while eye lens of short focal length and aperture and both are convergent. |
| 3. Final image is inverted. Virtual and enlarged and at a distance D to $\infty$ from the eye. | 3. Final image is inverted, virtual and enlarged at a distance D to $\infty$ from the eye. |
| 4. MP does not change appreciably if field and eye lens are interchanged [MP ~ $(LD / f_0 f_e)$] | 4. MP becomes ($1/m^2$) times of its initial value if objective and eye-lenses are interchanged as MP ~ $[f_0 / f_e]$ |
| 5. MP is increased by decreasing the focal length of both the lenses. | 5. MP is increased by increasing the focal length of objective lens (and by decreasing the focal length of eye-piece. |
| 6. RP is increased by decreasing the wavelength of light used. | 6. RP is increased by increasing the aperture of objective. |

**ILLUSTRATION–2.11**

If the tube length of an astronomical telescope is 105 cm and the magnifying power is 20 for the normal adjustment, calculate the focal length's of objective and eyepiece of telescope.

**SOLUTION:**

For the normal adjustment, i.e., for the normal vision (relaxed eye), The magnifying power is of magnitude

$$|M| = \frac{f_0}{f_e} = 20 \Rightarrow f_0 = 20 f_e$$

and the tube length is

$$f_0 + f_e = 105\,\text{cm}$$

Solving the above equations, we have

$$f_0 = 100\,\text{cm}, f_e = 5\,\text{cm}$$

**ILLUSTRATION–2.12**

A compound microscope has the magnifying power of magnitude 30. The focal length of it's eyepiece is 5 cm. If the final image is formed at the least distance of distinct vision $D = 25$ cm, calculate the magnification produced by the objective.

**SOLUTION:**

The magnifying power of compound microscope is

$$M = m_0 \times m_e = -\left(\frac{v_0}{f_0} - 1\right) \times \left(1 + \frac{D}{f_e}\right)$$

Therefore, the magnification produced by the objective is

$$m_0 = \frac{M}{m_e} = \frac{M}{\left(1 + \frac{D}{f_e}\right)} = \frac{-30}{\left(1 + \frac{25}{5}\right)} = -5$$

where the minus sign indicates that the image formed by the objective is inverted.

**ILLUSTRATION–2.13**

An astronomical telescope, consisting of an objective of focal length 60 cm and eyepiece of focal length 3 cm, is focussed on moon whose final image is formed at the least distance of distinct vision D = 25 cm from the eyepiece. If the angular size of moon is 0.5°, what will be the linear size of the final image of moon?

**SOLUTION:**

The magnifying power of telescope has the magnitude

$$|M| = \frac{f_0}{f_e}\left(1 + \frac{f_e}{D}\right) = \frac{60}{3}\left(1 + \frac{3}{25}\right) = 22.4$$

Then, the angular size of the final image of moon will be

$$= |M| \times 0.5° = 22.4 \times 0.5° = 11.2°$$

$$= 11.2 \times \frac{\pi}{180}\,\text{radian}$$

and it's linear size will be

$$= D\left(11.2 \times \frac{\pi}{180}\right)\text{cm}$$

$$= 25\left(11.2 \times \frac{\pi}{180}\right)\text{cm} = 25 \times 0.2\,\text{cm} = 5\,\text{cm}$$

**ILLUSTRATION–2.14**

The objective and eyepiece of a compound microscope, separated by 15 cm, have the focal lengths 2 cm and 3 cm, respectively. The final image of an object is formed at infinity. Find out the distances of the object and it's image formed in the objective, measured from the objective.

**SOLUTION :**

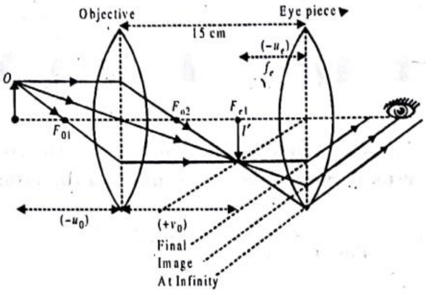



*Fig. 2.41*

Applying the lens formula for the eyepiece, we have

$$\frac{1}{v_e}-\frac{1}{u_e}=\frac{1}{f_e} \Rightarrow \frac{1}{-\infty}-\frac{1}{u_e}=\frac{1}{+3} \Rightarrow u_e=-3\text{ cm}$$

which means that the image $I'$ of object $O$ in the objective is formed at the first principal focus $f_{el}$ of eyepiece and hence, the distance of this from the objective is $v_0 = 15 - 3 = 12$ cm

Then, applying the lens formula for the objective, we have

$$\frac{1}{v_0}-\frac{1}{u_0}=\frac{1}{f_0} \Rightarrow \frac{1}{+12}-\frac{1}{u_0}=\frac{1}{+2} \Rightarrow \frac{1}{u_0}=\frac{1}{12}-\frac{1}{2} \Rightarrow u_0=-2.4\text{ cm}$$

i.e., the object distance from the objective is 2.4 cm

## LENS CAMERA

In it a converging lens whose aperture and distance from the film can be adjusted is used. Usually object is real and between $\infty$ and $2F$, so the image is real, inverted diminshed and between $F$ and $2F$ as shown in figure.

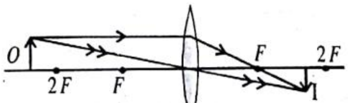



*Fig. 2.42*

In photography of an object, the image is first focused on the film by adjusting the distance between lens and film (called focusing). After focusing, aperture is set to a specific value (for desired effect) and then film is exposed to light for a given time through a shutter. $I$ is the intensity of light, $S$ is the light transmitting area of lens and $t$ is the exposure time, then for proper exposure, $I \times S \times t = \text{constant}$

However, light transmitting area of a lens is proportional to the square of its aperture $D$, so above expression reduces to

$I \times D \times t = \text{constant}$

(1) If aperture is kept fixed, $I \times t = \text{constant}$

(2) If intensity is kept fixed, $D^2 \times t = \text{constant}$ i.e., Times of exposure $\propto \dfrac{1}{(\text{Aperture})^2}$

Increasing the time of exposure by reducing the aperture increases the depth of field.

$f\text{-number} \propto \dfrac{\text{focal length}}{\text{Aperture}}$ ; Aperture $\propto \dfrac{1}{f\text{-number}}$

Time of exposure $\propto (f\text{-number})$

The following table will explain this relationship in detail.

| | | | | | |
|---|---|---|---|---|---|
| $f$-No. | 2 | $2.8 \approx 2\sqrt{2}$ | 4 | $5.6 \approx 4\sqrt{2}$ | 8 |
| $(f\text{-No.})^2$ | 4 | 8 | 16 | 32 | 64 |

# MISCELLANEOUS SOLVED EXAMPLES

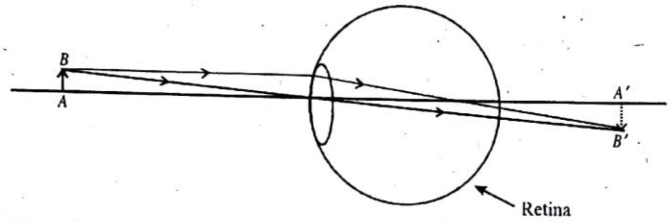
**1. A person needs a lens of power –5.5 dioptres for correcting his distant vision. For correcting his near vision he needs a lens of power +1.5 dioptre. What is the focal length of the lens required for correcting (i) distant vision, and (ii) near vision?**

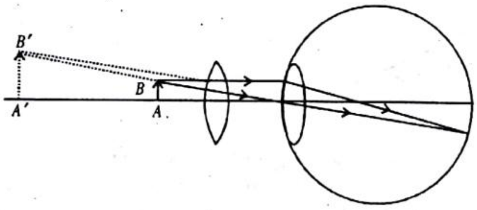
**Sol.** (i) Focal length of distance viewing = $\frac{1}{\text{Power}} = \frac{-100}{5.5}$ cm = −18cm.

(ii) Focal length in near vision = $\frac{100}{1.5}$ cm = 66.6 cm.

**2. Make a diagram to show how hypermetropia is corrected. The near point of a hypermetropic eye is 1 m. What is the power of the lens required to correct this defect? Assume that the near point of the normal eye is 25 cm.**

**Sol.**




To correct the defect, the image of an object at 25 cm should be brought at 100 cm.

$\therefore \quad \frac{1}{f} = \frac{1}{v} - \frac{1}{u} = \frac{1}{-100} - \frac{1}{-25}$ i.e., $\frac{1}{f} = \frac{-1}{100} + \frac{1}{25} = \frac{-1+4}{100} = \frac{3}{100}$

$\therefore \quad f = +\frac{100}{3} = +33.3$ cm

So, a convex lens of focal length 33.3 cm is required.

Power, $P = \frac{100}{33.3} = 3.0\,D$

**3. Why is a normal eye not able to see clearly the objects placed closer than 25 cm?**

**Sol.** The maximum accommodation of a normal eye is reached when the object is at a distance of 25 cm from the eye. The focal length of the eye lens cannot be decreased below this minimum limit. Thus, an object placed closer than 25 cm cannot be seen clearly by a normal eye because all the power of accommodation has already been exhausted.

**4. The angle of crown glass ($\mu$ =1.52) prism is 5°. What should be angle flint glass ($\mu$ = 1.63). Prism, so that the two prism together may be used in direct vision spectroscope ?**

**Sol.** For a direct vision spectroscope

$\delta_1 + \delta_2 = 0$

$\therefore \quad (\mu_1 - 1) A_1 + (\mu_2 - 1) A_2 = 0$

or $\quad A_2 = -\left(\frac{m_1 - A}{m_2 - 1}\right) A_1 = \left(\frac{1.52 - 1}{1.63 - 1}\right) \times 5° = -4.12°$

**5. The refracting angle of the prism is 60°. What is the angle of incidence for minimum deviation ? The refractive index of material of prism is $\sqrt{2}$.**

**Sol.** For minimum deviation

$r = A/2 = 60/2 = 30°$

From snell's law $\frac{\sin i}{\sin r} = \mu$ or $\quad \sqrt{2} = \frac{\sin i}{\sin 30^0}$

$\therefore \quad \sin i = \frac{1}{2} \times \sqrt{2} = \frac{1}{\sqrt{2}} = \sin 45° \quad$ or $\quad i = 45°$

**6. A farsighted person cannot focus clearly an objects that are less than 145 cm from his eyes. To correct this problem, the person wear eyeglasses that are located 2.0 cm in front of his eyes. Determine the focal length that will permit this person to read a newspaper at a distance of 32.0 cm from his eyes.**

**Sol.** The near point is 145 cm and eyeglasses are 2.0 cm in front of the eyes. Therefore, $v = -143$ cm. The object is placed 32.0 cm from the eyes so $u = +30.0$ cm. The focal length is obtained from equation

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v} = \frac{1}{(30.0\,\text{cm})} + \frac{1}{-143\,\text{cm}} = 0.026\,\text{cm}^{-1}$$

Hence, $f = 38$ cm.

**7. A certain eye has a near point of 11.0 cm. and a far point of 15.0 cm. (a) What is the refractive power of the lens that is required to place the far point at infinity ? (b) What is the near point distance when the person uses the lens fount in part (a) ? (c) What is the refractive power of the lens required to yield a near-point distance of 25 cm.**

**Sol.** (a) We want to move the far point to infinity, so

$$\frac{1}{f} = \frac{1}{\infty} + \frac{1}{(-0.15\text{m})} = -6.7 \text{ diopters}$$

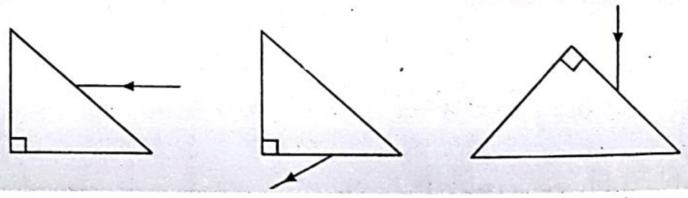
(b) We have, $\frac{1}{u} = \frac{1}{f} - \frac{1}{v} = -6.7\,\text{m}^{-1} - \frac{1}{-0.11\,\text{m}} = 2.4\,\text{m}^{-1}$

So that $u = 42$ cm.

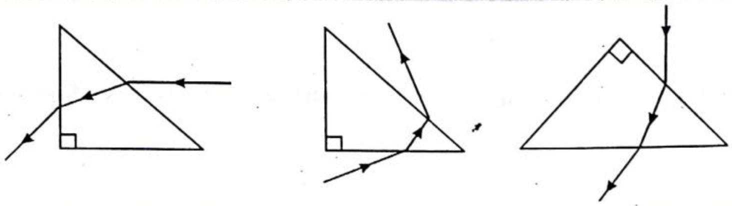
(c) For the near point at 25 cm :

$$\frac{1}{f} = \frac{1}{0.25\,\text{m}} + \frac{1}{-0.11\,\text{m}} = -5.1 \text{ diopters}$$

**8. Complete the path of the monochromatic ray of light in each of the right angled isosceles triangle. Critical angle for the glass is 42° (figure).**



**Sol.**



**9. A figure divided into squares, each of size 1mm², is being viewed at a distance of 9 cm through a magnifying glass (a converging lens of focal length 10 cm) held close to the eye. (i) What is the magnification (image size/object size) produced by the lens ? How much is the area of each square in the virtual image ?**
**(ii) What is the angular magnification (magnifying power) of the lens ? (iii) Is the magnification in (i) equal to the magnifying power in (ii) ? Explain.**

**Sol.** (i) $u = -9$ cm, $f = 10$ cm. Now, $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$ or $\frac{1}{v} = \frac{1}{f} + \frac{1}{u}$

or, $\frac{1}{v} = \frac{1}{10} + \frac{1}{-9} = \frac{-9+10}{-90} = -\frac{1}{90}$ or $v = -90$ cm.

Magnification $= \frac{v}{x} = \frac{-90}{-9} = 10$

Since, magnification is 10 therefore the area of each square in the virtual image is $10 \times 10 \times 1$ mm² i.e., 100 mm².

(ii) Angular magnification $= \frac{D}{u} = \frac{-25}{-9} = 2.78$

(iii) No. Magnification of an image by a lens and angular magnification (or magnifying power) of an optical instrument are two separate things. The latter is the ratio of the angular size of the object (which is equal to the angular size of the image even if the image is magnified) to the angular size of the object if placed at the near point (25 cm). Thus, magnification magnitude is $\left|\frac{v}{u}\right|$ and magnifying power is $\frac{25}{|u|}$. Only when the image is located at the near point ($|v| = 25$ cm), are the two quantities equal.

**10. A lady uses +1.5D glasses to have normal vision from 25 cm onwards. She uses a 20D lens as a simple microscope to see an object. Calculate the maximum magnifying power if she uses the microscope**
**(a) together with her glass (b) without the glass.**

**Sol.** (a) $M = 1 + \frac{D}{f} = 1 + PD = 1 + 20 \times \frac{1}{4} = 6$

(b) focal length of glasses $= \frac{100}{1.5} = \frac{1000}{15} = \frac{200}{3}$

$\frac{1}{v} - \frac{1}{-25} = \frac{3}{100}$ or $\frac{1}{v} = \frac{3}{200} - \frac{1}{25} = \frac{3-8}{200} = -\frac{5}{200} = -\frac{1}{40}$

$v = -40$ cm.

Now, $M = 1 + Pv = 1 + 20\left(\frac{40}{100}\right) = 1 + 8 = 9$

# 1 EXERCISE

## FIB Fill in the Blanks :

**DIRECTIONS:** *Complete the following statements with an appropriate word / term to be filled in the blank space(s).*

1. The coloured diaphragm between the cornea and the lens is ...............
2. The middle point of the iris has a hole, which is called ............
3. The screen on which the image is formed by the lens system of the human eye is called ...............
4. .............. responds to the intensity of light.
5. ............... respond to colour by generating electrical nerve pulses.
6. For young adult with normal vision, least distance of distict vision = ............
7. The closest distance at which the eye can focus clearly is called the .................
8. For a normal eye, the range of vision is from ................
9. The eye which suffers from myopia as well as from hypermetropia is said to suffer from ....................
10. The eye which cannot simultaneously see with the same distinctness all objects or lines making different inclinations is said to suffer from ..................
11. The defect of the eye due to which a person is unable to distinguish between certain colours, known as .............
12. Newton demonstrated that white light is made up of ........... constituent colours.
13. The phenomenon of splitting of white light into its constituent colours is called ...............
14. The band of colours produced on the screen is called .........
15. The ability of the eye to focus both near and distant objects, by adjusting its focal length, is called the .........
16. The smallest distance, at which the eye can see objects clearly without strain, is called the ............ of the eye.
17. The common refractive defects of vision include .........., ............. and ..............
18. The splitting of white light into its component colours is called ....................
19. .................. causes the blue colour of sky and the reddening of the Sun at sunrise and sunset.
20. Sunlight comprises ............... colours.
21. The wavelength of violet colour is ..................
22. The wavelength of red colour is ..................
23. In the minimum deviation position, the path of ray of light entering a prism is such that the angle of ................ is ............. to the angle of emergence; also the refracted ray in the prism is ........... to the base of the prism

## T/F True / False :

**DIRECTIONS:** *Read the following statements and write your answer as true or false.*

1. Lens which is used for correcting the presbyopia defect of the eye is concave.
2. The colour that deviates maximum while passing through a glass prism is violet.
3. Water droplets act as tiny prism in the formation of rainbow.
4. The transparent spherical membrane covering the front of the eye is known as cornea.
5. The eye which can see near object clearly is said to suffer from hypermetropia.
6. The eye which cannot see distant objects clearly is said to suffer from myopia.
7. Colour blindness is a genetic disorder which occurs by inheritance.
8. In Myopia the image of distant objects is focussed before the retina.
9. Hypermetropia is corrected by using a convex lens of suitable power.
10. The refractive index of diamond is 2.4. Its critical angle is 24° 38'. (twenty four degree, and thirty eight minutes)
11. For total internal reflection to take place, the angle of incidence in the given (denser) medium must be less than the critical angle for that medium.
12. In the minimum deviation position of a prism, the refracted ray is always parallel to its base.
13. A person suffering from myopia cannot see distant objects clearly.
14. The focal length of a given lens depends on the surrounding medium.
15. Prismatic periscopes use the principle of total internal reflection.
16. A dentist uses a convex mirror to view the inner parts of a patient's mouth.
17. The solar spectrum in general is an absorption spectrum.

## Match the Following :

**DIRECTIONS (Qs. 1-3) :** *Each question contains statements given in two columns which have to be matched. Statements (A, B, C, D) in column I have to be matched with statements (p, q, r, s) in column II.*

1. Match the following :

| Column I | Column II |
|---|---|
| (A) Inverted crown-flint glass prism | (p) Deviation $\propto \frac{1}{\text{dispersive power}}$ |
| (B) Achromatism | (q) Deviation without dispersion |
| (C) Hollow prism | (r) Absence of chromatic aberration |
| (D) Glass slab | (s) Dispersion without deviation |

2. Column II gives lens that can be use to correct the defect of vision given in column I, match them correctly.

| Column I | Column II |
|---|---|
| (A) Myopia | (p) convex lens |
| (B) Hyperopia | (q) concave lens |
| (C) Astigmatism | (r) cylindrical lens |
| (D) Presbyopia | (s) bi-focal lens |

3. Match the following :

| Column I | Column II |
|---|---|
| (A) Plane mirror | (p) Primary colours |
| (B) Convex lens | (q) $4\pi$ steradian |
| (C) Spectroscope | (r) Incoherent scattering |
| (D) Atmospheric scattering of light | (s) Magnification always one |
| (E) RBRBG | (t) Terrestrial telescope |
| (F) Optic fibre | (u) Burglar alarm |
| (G) Sol Solid angle in a sphere | (v) Virtual and magnified image |
| (H) Photo electric effect | (w) Blue colour of effect the sky |
| (I) Raman effect | (x) Observing and studying spectrum |
| (J) Erecting lens | (y) Total internal reflection |

## Very Short Answer Questions :

**DIRECTIONS :** *Give answer in one word or one sentence.*

1. When a monochromatic light passes through a prism, will it show dispersion?
2. Will a star appear to twinkle if seen from free space (say moon)?
3. What do you mean by a pure spectrum?
4. What is the common name for short sightedness?
5. Name the defect which is corrected by using an astigmatic lens.
6. Name a natural spectrum.
7. Name the ability of the eye to see objects at all distances.
8. Will a star appear to twinkle if seen from free space (say moon) ?
9. Suppose you point to a wall with your arm extended. Then you sweep your arm around, making an angle of about 42° to the wall. If you rotate your arm in a full circle while keeping the same angle, what shape does your arm describe? What shape on the wall does your finger sweep out?
10. If light travelled at the same speed in raindrops as it does in air, would we have rainbows?
11. What prevents rainbows from being seen as complete circles?
12. What is responsible for the rainbow-coloured fringe commonly seen at the edges of a spot of white light from the beam of lantern or slide projector?
13. What is the essential condition for observing a rainbow ?
14. Does a beam of light give spectrum on passing through a hollow prism containing air, explain ?
15. Why does a secondary rainbow have inverted colours ?
16. A short-sighted person may read a book without spectacles. Comment.
17. A hypermetropic person has problem in driving without spectacles, comment on this.
18. A person looking at a mesh of crossed wires is able to see the vertical wires more distinctly than the horizontal wires. Why ? How can it be corrected ?
19. A short-sighted person cannot see clearly beyond 2 m. Calculate power of the lens required to correct his eye to normal vision.
20. A myopic person can see things clearly only when they lie between 10 cm and 100 cm from his eye. Which lens will enable him to see the moon clearly ?
21. A person can see the objects lying between 25 cm and 10 m from his eye. His vision can be corrected by using lens of power – 0.1 D. Is the statement true or false ?
22. Which is the most developed sensory organ of a human being ?
23. Which part of the eye causes the first refraction ?
24. Which part of the eye gives the characteristic colour of the eye ?
25. What is the function of the ciliary muscles ?
26. Where are fovea and blind spot located in the eye ?
27. How does the size of the image on the retina change as an object is brought nearer and nearer to the eye?
28. What is the distance at which a watch repairer holds the watch when he is wearing a magnifying glass, if his distance of most distinct vision is 30 cm ? Assume that he is not aware of the action of a convex lens.
29. What is meant by persistence of vision ?

## SQA Short Answer Questions :

**DIRECTIONS :** *Give answer in 2-3 sentences.*

1. Can a beam of white light when passed through a hollow prism give spectrum ? Explain.
2. What is Cataract?
3. What is colour blindness?
4. How do we see colours?
5. A person having a myopic eye uses a concave lens of focal length 50 cm. What is the power of the lens ?
6. What are fibre cables?
7. Why do different coloured rays deviate differently in the prism?
8. Why does a diamond sparkle?
9. Who do stars twinkle on a clear night?
10. A person having the nearest distance of distinct vision of 32 cm uses a reading lens of 8 cm focal length. What is the magnification of his reading lens ?
11. A man who wears glasses of power 3 dioptre must hold a newspaper at least 25 cm away to see the print clearly. How far away would the newspaper have to be if he took off the glasses and still wanted clear vision?
12. Why does it take some time to see objects in a dim room when you enter the room from bright sunlight outside ?
13. Does a single raindrop illuminated by sunlight disperse a spectrum of colours? Does a viewer see a spectrum from a single far away drop?
14. Two observers standing apart from one another do not see the "same" rainbow. Explain.
15. How is a rainbow similar to the halo sometimes seen around the moon on a frosty night? How are seen around the moon on a frosty night? How are rainbows and halos different?
16. A 45 year old person is suffering from a defect in his vision due to which he uses spectacles of bi-focal lenses.
    (a) Which defect he is suffering from?
    (b) What is a bi-focal lens?
17. What is dark adaptation of the eye?
18. A person having short sight (near sight) unable to see clearly beyond 2 m develops presbyopia by which he is unable to read a book held closer than 1m. Prescribe lenses of suitable power for distant vision and near vision.

## LAQ Long Answer Questions :

**DIRECTIONS :** *Give answer in four to five sentences.*

1. Why does it take some time to see objects in a dim room when you enter the room from bright sunlight outside?
2. Explain the construction and working of a compound microscope with a ray diagram. Derive the expression for magnification when image is formed at infinity.
3. Explain the formation of mirages.
4. A prism causes dispersion of white light while a rectangular glass block does not. Explain.
5. How will you investigate the existence of the radiation beyond the red and violet extremes of the spectrum?
6. When yellow paint and blue paint are mixed we get green colour. When yellow light and blue light are mixed, white light is obtained. Give reasons.
7. Explain why in day light an object appears red when seen through a red glass and black when seen through a blue glass?
8. How would you show the presence of UV and IR rays in the spectrum?

# 2 EXERCISE

## MCQ Multiple Choice Questions :

**DIRECTIONS:** *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONLY ONE is correct.*

1. Angle of deviation $(\delta)$ by a prism (refractive index $= \mu$, and supposing the angle of prism $A$ to be small) can be given by
   (a) $\delta = (\mu - 1)A$ (b) $\delta = (\mu + 1)A$
   (c) $\delta = \dfrac{\sin(A+\delta)/2}{\sin(A/2)}$ (d) $\delta = \dfrac{\mu - 1}{\mu + 1}A$

2. The human eye forms the image of an object at its
   (a) cornea (b) iris
   (c) pupil (d) retina

3. The least distance of distinct vision for a young adult with normal vision is about
   (a) 25 m (b) 2.5 cm
   (c) 25 cm (d) 2.5 m

4. The change in focal length of an eye lens is caused by the action of the
   (a) pupil (b) retina
   (c) ciliary muscles (d) iris

5. Prism angle of a prism is $10^\circ$. Their refractive index for red & violet colour is 1.51 and 1.52, respectively. Then dispersive power will be
   (a) 0.5 (b) 0.15
   (c) 0.019 (d) 0.032

6. Prism angle and refractive index for a prism for a $60^\circ$ and 1.414. Angle of minimum deviation will be
   (a) $15^\circ$ (b) $30^\circ$
   (c) $45^\circ$ (d) $60^\circ$

7. Diameter of the moon is $3.5 \times 10^3$ km and its distance from earth is $3.8 \times 10^5$ km. It is seen by a telescope whose objective and eyepiece have focal lengths 4m and 10cm respectively. The angular diameter of the image of the moon will be nearly
   (a) $5^\circ$ (b) $10^\circ$
   (c) $20^\circ$ (d) $25^\circ$

8. A telescope consisting of an objective of focal length 60 cm and a single–lens eye-piece of focal length 5 cm is focussed at a distant object in such a way that parallel rays emerge from the eye-piece. If the object subtends an angle of $2^\circ$ at the objective, then the angular width of the image will be
   (a) $10^\circ$ (b) $24^\circ$
   (c) $50^\circ$ (d) $1/6^\circ$

9. A near sighted person cannot see distinctly beyond 50 cm from his eye. The power in diopter of spectacle lenses which will enable him to see distant objects clearly is
   (a) +50 (b) –50
   (c) +2 (d) –2

10. The following one is not a primary colour
    (a) Yellow (b) Red
    (c) Green (d) Blue

11. Fraunhofer lines in the sun's spectrum are present because
    (a) Vapours of certain elements present in the atmosphere absorb certain colours
    (b) The temperature of the sun is very high
    (c) The sun does emit certain light
    (d) Certain elements present in the sun interfere

12. When a mirror is rotated an angle the reflected ray moves through double that angle, the instrument based on the above principle is
    (a) Periscope (b) Odometer
    (c) Refractometer (d) Sextant

13. Rainbow is caused due to
    (a) Reflection of sun light air
    (b) Dispersion of sun light from water drops
    (c) Refraction of sun light from water drops
    (d) Diffraction of sun rays from water drops

14. In the visible spectrum the colour having the shortest wavelength is
    (a) Green (b) Red
    (c) Violet (d) Blue

15. The splitting of white light into several colours on passing through a glass prism is due to
    (a) refraction (b) reflection
    (c) interference (d) diffraction

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**16.** At the moment dew formation starts on a cool night, the air
(a) Must loose all water vapour
(b) Must remain unsaturated
(c) Must get mixed up with some other vapour
(d) Must become saturated

**17.** At sun rise or at sun set the sun appears to be reddish while at mid-day it looks white. This is because
(a) Scattering due to dust particles and air molecules causes this phenomenon
(b) The sun is cooler at sun rise or at sunset
(c) Refraction causes this phenomenon
(d) Diffraction sends red rays to the earth at these times.

**18.** Sometimes blurred and less sharply defined images are formed. This defect is called
(a) Chromatic aberration (b) Spherical aberration
(c) Blurred lens (d) None of the above

**19.** A person cannot see objects clearly which are nearer than 75 cms from his eyes, the disease he is suffering from is
(a) Astigmatism (b) Myopia
(c) Hypermetropia (d) Presbyopia

**20.** On entering a glass prism, sun rays are
(a) Deviated but not dispersed
(b) Deviated and dispersed
(c) Dispersed but not deviated
(d) Neither deviated nor dispersed.

**21.** A piece of cloth looks red in sun light. It is held in the blue portion of a solar spectrum, it will appear
(a) red (b) black
(c) blue (d) white

**22.** The angle of minimum deviation of a ray of light of glass prism is greatest for the light of colour
(a) violet (b) orange
(c) yellow (d) red

**23.** To get line spectrum, the substances are excited in their
(a) solid state (b) molecular state
(c) gaseous state (d) atomic state

**24.** A fish looking up through the water sees the outside world contained in a circular horizon. If the refractive index of water is 4/3 and the fish is 12 cm below the surface, the radius of this circle in cm is
(a) $36\sqrt{5}$ (b) $4\sqrt{5}$
(c) $36\sqrt{7}$ (d) $36/\sqrt{7}$

**25.** The frequency of light whose wavelength is 5000 Å is
(a) $15 \times 10^{13}$ cycles per second
(b) 5000 cycles per second
(c) $6 \times 10^{14}$ cycles per second
(d) $15 \times 10^{16}$ cycles per second

**26.** The pupil of the eye changes in size to adjust for
(a) objects at different distances
(b) objects of different sizes
(c) different colors
(d) different amounts of light

**27.** To use a magnifying glass, the object should be placed
(a) as close to the lens as possible
(b) just within the lens' focal point
(c) just beyond the focal point
(d) some distance beyond the focal point

**28.** A camera employs a ............ lens to form .......... images
(a) diverging ........ real
(b) diverging ........ virtual
(c) converging ... real
(d) converging ... virtual

**29.** In the eye, the position of the image on the retina is adjusted by changing the
(a) position of the lens
(c) diameter of the pupil
(b) focal length of the lens
(d) length of the eyeball

**30.** What power lens is needed to correct for nearsightedness where the uncorrected far point is 250 cm?
(a) +2.5 diopters (b) –2.5 diopters
(c) + 0.4 diopters (d) –0.4 diopters

**31.** What power lens is needed to correct for farsightedness where the uncorrected near point is 250 cm?
(a) + 3.6 diopters (b) – 3.6 diopters
(c) + 0.28 diopters (d) – 0.28 diopters

**32.** In a room, artificial rain is produced at one end and a strong source of white light is switched on at the other end. To observe the rainbow an observer must
(a) Look anywhere in the room
(b) Look towards the source
(c) Look towards the raindrops
(d) Look in a direction equally inclined to the source of raindrops

**33.** For which of the following pairs the critical angle is smallest
(a) Water to air (b) Glass to water
(c) Glass to air (d) Glass to glass

**34.** For which colour the critical angle is maximum in water-air system
(a) Red
(b) Violet
(c) Yellow
(d) It is same for all colours

**35.** A direct vision spectrometer uses the phenomenon of
(a) Diffraction
(b) Interference without deviation
(c) Dispersion without deviation
(d) Deviation without dispersion

**36.** Astigmatism can be corrected by
(a) Bifocal lenses
(b) Cylindrical lenses
(c) Concave lenses
(d) Planoconvex lenses

**37.** For seeing a cricket match, we prefer binoculars to the terrestrial telescope, because
(a) Binoculars give three-dimensional view
(b) Terrestrial telescope gives inverted image
(c) To avoid chromatic aberration
(d) To have larger magnification

**38.** The electromagnetic radiation of frequency $n$, wavelength $\lambda$, travelling with velocity $v$ in air, enters a glass slab of refractive index $\mu$. The frequency, wavelength and velocity of the radiation in the glass slab will be, respectively –
(a) $n, \frac{\lambda}{\mu}, v$ (b) $\frac{n}{\mu}, \lambda, \frac{v}{\mu}$
(c) $n, \frac{\lambda}{\mu}, \frac{v}{\mu}$ (d) $\frac{n}{\mu}, \frac{\lambda}{\mu}, \frac{v}{\mu}$

**39.** The convex lens is not used
(a) in camera
(b) as glasses to correct for short sight
(c) as glasses to correct for light sight
(d) all of the above

**40.** When blue light is used in a thin convex lens then the focal length is found to be $f$. If instead red light is used, then the focal length will be
(a) equal to $f$
(b) less than $f$
(c) greater than $f$
(d) nothing can be predicted

**41.** One of the refracting surfaces of a prism is silvered, and the angle of prism is A. It is found that a ray of light incident at an angle of incidence 2A after suffering refraction return back through the same path due to reflection from the second silvered refracting surface. Then the refractive index of the material of the prism is
(a) $2 \sin A$ (b) $2 \cos A$
(c) $\tan A$ (d) $\frac{1}{2} \cos A$

**42.** A diver at a depth of 12 m in water ($\mu = 4/3$) sees the sky in a cone of semi-vertical angle
(a) $\sin^{-1}(4/3)$ (b) $\tan^{-1}(4/3)$
(c) $\sin^{-1}(3/4)$ (d) $90°$

**43.** The refractive index of water is 4/3 and that of glass is 5/3. What will be the critical angle for the ray of light entering water from the glass
(a) $\sin^{-1}(4/5)$ (b) $\sin^{-1}(5/4)$
(c) $\sin^{-1}(1/2)$ (d) $\sin^{-1}(2/1)$

**44.** Relation between critical angles of water and glass is
(a) $C_w > C_g$ (b) $C_w < C_g$
(c) $C_w = C_g$ (d) $C_w = C_g = 0$

**45.** Critical angle for light going from medium (i) to (ii) is $\theta$. The speed of light in medium (i) is $v$ then speed in medium (ii) is
(a) $v(1-\cos\theta)$ (b) $v/\sin\theta$
(c) $v/\cos\theta$ (d) $v(1-\sin\theta)$

**46.** If light travels a distance $x$ in $t_1$ sec. in air and $10x$ distance in $t_2$ sec. in a medium, the critical angle of the medium will be
(a) $\tan^{-1}\left(\frac{t_1}{t_2}\right)$ (b) $\sin^{-1}\left(\frac{t_1}{t_2}\right)$
(c) $\sin^{-1}\left(\frac{10t_1}{t_2}\right)$ (d) $\tan^{-1}\left(\frac{10t_1}{t_2}\right)$

**47.** Dispersion is the term used to describe
(a) the propagation of light in straight lines
(b) The splitting of a beam of light into component colours
(c) The bending of a beam of light when it strikes a mirror
(d) The change that takes place in white light after passage through red glass.

**48.** In a glass prism
(a) Blue light is dispersed more than red light
(b) Red light is dispersed more than blue light
(c) Both red light and blue light are equally dispersed
(d) None of these

49. Deviation $\delta$ produced by a prism of refractive index $\mu$ and small angle A is given by
(a) $\delta = (\mu - 1) A$ (b) $\delta = (\mu + 1) A$
(c) $\delta = (A - 1) \mu$ (d) $\delta = (A + 1) \mu$

50. If for a given prism the angle of incidence is changed from 0° to 90°, the angle of deviation
(a) Increases
(b) Decreases
(c) First decreases and then increases
(d) First increases and then decreases

51. Consider telecommunication through optical fibres. Which of the following statement is not true
(a) Optical fibres can be of graded refractive index
(b) Optical fibres have extremely low transmission loss
(c) Optical fibres are subject to electromagnetic interference from outside
(d) Optical fibres may have homogeneous core with a suitable cladding

52. The refracting angle of a prism is A and the refractive index of the prism is cot A/2. The angle of minimum deviation is
(a) $180° - 3A$ (b) $180° + 2A$
(c) $90° - A$ (d) $180° - 2A$

53. A ray is incident at an angle of incidence i on one face of a prism of small angle *A* and emerges normally from the opposite surface. If the refractive index of the material of the prism is $\mu$, the angle of incidence i is nearly equal to
(a) $A/\mu$ (b) $A/2\mu$
(c) $\mu A$ (d) $\mu A/2$

54. An optician while testing the eyes finds the vision of a patient to be 6/12. By this he means that
(a) The person can read the letters of 6 inches from a distance of 12 m
(b) The person can read the letters of 12 inches from 6 m
(c) The person can read the letters of 6 m which the normal eye can read from 12 m
(d) The focal length of eye lens had become half that of the normal eye

55. A person cannot see objects clearly beyond 50 cm. The power of the lens to correct the vision is
(a) +5 D (b) −0.5 D
(c) −2 D (d) +2 D

56. A long sighted person has a minimum distance of distinct vision of 50 cm. He wants to reduce it to 25 cm. He should use a
(a) Concave lens of focal length 50 cm
(b) Convex lens of focal length 25 cm
(c) Convex lens of focal length 50 cm
(d) Concave lens of focal length 25 cm

57. A long-sighted person cannot see objects clearly at a distance less than 40 cm. from his eye. The power of the lens needed to read an object at 25 cm. is
(a) −2.5 D (b) +2.5 D
(c) −6.25 D (d) +1.5 D

58. In which of the following cases, is total internal reflection not possible
(a) A ray incident from water to glass
(b) A ray incident from glass to water
(c) A ray incident from glass to air
(d) A ray incident from water to air

59. Critical angle of light passing from glass to air is maximum for
(a) violet (b) blue
(c) yellow (d) red

60. A mirage occurs because
(a) The refractive index of atmosphere increases with height
(b) The refractive index of atmosphere decreases with height
(c) The hot ground acts like a mirror
(d) Refractive index remains constant with height

61. A well cut diamond appears bright because
(a) Of reflection of light
(b) Of dispersion of light
(c) The total internal reflection
(d) Of refraction of light

62. Twinkling of stars is on account of
(a) Large distance of stars and storms in air
(b) Small size of stars
(c) Large size of stars
(d) Large distance of stars and fluctuations in the density of air.

63. You are under the water in a clear lake looking at the surface and see the image of a fish due to total internal reflection. What is the minimum angle that the light leaving the fish makes with the normal to the surface of the lake?
(a) 42° (b) 53°
(c) 49° (d) 37°

64. A ray of light passing through a prism having $\mu = \sqrt{2}$ suffers minimum deviation. If angle of incident is double the angle of refraction within prism, than angle of prism is
(a) 30° (b) 45°
(c) 60° (d) 90°

65. White light is incident at an angle to the surface of a triangular piece of glass. Which color of light deviates most from its original path after leaving the glass?
(a) red (b) orange
(c) green (d) blue

## More than One Correct :

**DIRECTIONS :** *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONE OR MORE may be correct.*

**1.** The human eye can focus objects at different distances by adjusting the focal length of the eye lens. Choose those options which are not accountable for this happening.
(a) presbyopia (b) accommodation
(c) near-sightedness (d) far-sightedness

**2.** The change in focal length of an eye lens is not caused by the action of the
(a) pupil (b) retina
(c) ciliary muscles (d) iris

**3.** The following is/are a primary colour
(a) Yellow (b) Red
(c) Green (d) Blue

**4.** When a mirror is rotated an angle the reflected ray moves through double that angle, the instruments which are not based on the above principle, are
(a) Periscope (b) Odometer
(c) Refractometer (d) Sextant

**5.** A combination is made of two lenses of focal length $f$ and $f'$ in contact, the dispersive powers of the material of the lenses are $\omega$ and $\omega'$. The combination is not achromatic when
(a) $\omega = \omega_0, \omega' = 2\omega_0, f' = 2f$
(b) $\omega = \omega_0, \omega' = 2\omega_0, f' = f/2$
(c) $\omega = \omega_0, \omega' = 2\omega_0, f' = -f/2$
(d) $\omega = \omega_0, \omega' = 2\omega_0, f' = -2f$

**6.** In case of hypermetropia
(a) The image of near objects is formed in front of retina
(b) The image of near objects is formed behind the retina
(c) A concave lens should be used for correction
(d) A convex lens cannot be used for correction

**7.** Astigmatism is / are
(a) Bifocal lenses (b) Cylindrical lenses
(c) Concave lenses (d) Planoconvex lenses

**8.** The defect that may occur in a lens are
(a) spherical aberration and chromatic aberration
(b) coma and astigmation
(c) distortion
(d) none of the above

**9.** Out of the following, which statements are correct
(a) Sunlight filtering through a tree often makes circular patches on the ground because sun is round
(b) A beam of white light passing through a hollow prism gives no spectrum
(c) The number of images observable between two parallel plane mirrors is infinite
(d) A virtual object placed between the pole and the principal focus of a convex mirror produces an image which is virtual, diminished and upright.

**10.** Due to refraction of light in atmosphere
(a) Stars appear to twinkle
(b) The sun appears to be oval in morning and evening
(c) The period of visibility of the sun is increased
(d) The phenomena of mirage and looming take place

**11.** White light is incident on an equilateral prism. In the position of minimum deviation
(a) Angle of incidence is equal to angle of emergence
(b) The ray inside the prism is parallel to its base
(c) The angle of refraction inside the prism is equal to the angle of prism
(d) The dispersion of all colours is same

**12.** Out of the following, select the correct statements
(a) Refractive index varies inversely as the fourth power of the wavelength of light.
(b) When the moon is near the horizon, it appears bigger. This is due to optical illusion.
(c) The colour of light which travels with the maximum speed in glass is red.
(d) If sun is shining brightly in one part of the sky after rain, two rainbows are usually observed.

**13.** In which of the following cases, is total internal reflection possible
(a) A ray incident from water to glass
(b) A ray incident from glass to water
(c) A ray incident from glass to air
(d) A ray incident from water to air

**14.** The optical phenomenon which Newton's theory of light failed to explain is
(a) interference (b) polarization
(c) diffraction (d) none of the above three

**15.** A convex mirror is not used
(a) by a dentist
(b) for shaving
(c) as a rear view mirror in vehicles
(d) as a light reflector for obtaining a parallel beam of light.

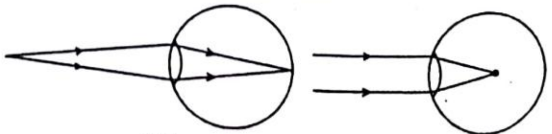
**16.** Spectrometer is used to measure
(a) angle of prism
(b) refractive index of material of a prism
(c) the dispersion
(d) none of the above

## Fill in the Passage :

**DIRECTIONS :** *Complete the following passage(s) with an appropriate word/term to be filled in the blank spaces.*

**I.**

| | | | | |
|---|---|---|---|---|
| Hypermetropia | myopia | presbyopia | nearby | distant |
| convex | concave | cylindrical | infront of | behind |



Object at near point    Object at far point

The figure shown demonstrates .......1........ . It is the in ability to see .......2........ objects. This defect occurs due to slight elongation of the eye ball. A a result the distance between eye lens and retina is greater (focal length of lens decreases) and the image is formed .......3........ the retina. This defect can be corrected using a .......4........ lens of suitable focal length.

**2.**

| | | | |
|---|---|---|---|
| incidence | refraction | critical | interference |
| diffraction | rarer | total internal reflection | |
| denser | mirage | spectrum | |

When light passes from one medium to other, it bends. Suppose a ray of light is made incident at a certain angle of incidence 'i'. At this angle of incidence, the ray gets refracted. Now 'i' is increased slowly and continuously. As 'i' approaches a certain value greater than .......1....... angle, the ray reflects back in the same medium. This phenomenon is called the .......2....... . For the phenomenon to take place, the light must pass from a .......3....... to a .......4....... medium. The formation of .......5....... is due to this phenomenon.

## PBQ Passage Based Questions :

**DIRECTIONS :** *Study the given paragraph(s) and answer the following questions.*

### Passage-I

Image formation by thin lenses follows the reaction $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$.

We know that for real objects, a concave lens forms a virtual image whereas a convex lens forms an image that could be real or virtual. Consider a lens and a small object placed at right-angles to its optic axis at a position (1) such that the image formed is six times magnified. The object is now shifted away from the lens to another position (2) at a distance 12cm, from position (1) and an image, that is magnified two times but of the same nature as in the earlier case is obtained. Shifting the position of object from (2) to a third position (3) results in an image that is 4 times reduced in size. At all the positions so far, length of the object is kept perpendicular to the optic axis.

**1.** Distance of positions (1) and (2) of the object from the optic centre are, respectively
(a) 42 cm, 54 cm (b) 54 cm, 42 cm
(c) 60 cm, 48 cm (d) 72 cm, 60 cm

**2.** Distance of position (3) from optic centre is
(a) 150 cm (b) 180 cm
(c) 75 cm (d) 60 cm

**3.** Focal length of lens is
(a) 36 cm (b) 48 cm
(c) 75 cm (d) 60 cm

### Passage-II

The ciliary muscles of eye control the curvature of the lens in the eye and hence can alter the effective focal length of the system. When the muscles are fully relaxed, the focal length is maximum. When the muscles are strained the curvature of lens increases (that means radius of curvature decreases) and focal length decreases. For a clear vision the image must be on retina. The image distance is therefore fixed for clear vision and it equals the distance of retina from eye-lens. It is about 2.5 cm for a grown-up person.

A person can theoretically have clear vision of objects situated at any large distance from the eye. The smallest distance at which a person can clearly see is related to minimum possible focal length. The ciliary muscles are most strained in this position. For an average grown-up person minimum distance of object should be around 25 cm.

A person suffering for eye defects uses spectacles (Eye glass). The function of lens of spectacles is to form the image of the objects within the range in which person can see clearly. The image of the spectacle-lens becomes object for eye-lens and whose image is formed on retina.

The number of spectacle-lens used for the remedy of eye defect is decided by the power of the lens required and the number of spectacle-lens is equal to the numerical value of the power of lens with sign. For example power of lens required is +3D (converging lens of focal length 100/3 cm) then number of lens will be +3.

For all the calculations required you can use the lens formula and lens maker's formula. Assume that the eye lens is equiconvex lens. Neglect the distance between eye lens and the spectacle lens.

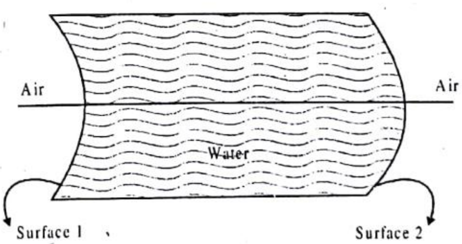
**1.** Minimum focal length of eye lens of a normal person is
(a) 25 cm (b) 2.5 cm
(c) 25/9 cm (d) 25/11 cm

**2.** Maximum focal length of eye lens of normal person is
(a) 25 cm (b) 2.5 cm
(c) 25/9 cm (d) 25/11 cm

**3.** A nearsighted man can clearly see object only upto a distance of 100 cm and not beyond this. The number of the spectacles lens necessary for the remedy of this defect will be
(a) +1 (b) – 1
(c) +3 (d) – 3

### Passage-III

All objects referred to the subsequent problems lie on the principal axis.



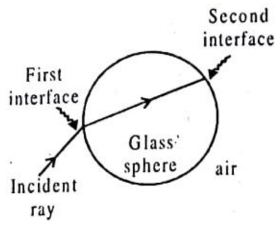
1. If light is incident on surface 1 from left, the image formed after the first refraction is definitely
   (a) real for a real object (b) virtual for a real object
   (c) real for a virtual object (d) virtual for a virtual object
2. In above question if the object is real, then the final image formed after two refractions
   (a) may be real (b) may be virtual
   (c) must be virtual (d) Both (a) and (b)
3. If light is incident on surface 2 from right then which of the following is true for image formed after a single refraction
   (a) Real object will result in a real image
   (b) Virtual object will result in a virtual image
   (c) Real object will result in a virtual image
   (d) Virtual object will result in a real image

## A&R Assertion & Reason :

**DIRECTIONS :** *Each of these questions contains an Assertion followed by reason. Read them carefully and answer the question on the basis of following options. You have to select the one that best describes the two statements.*

(a) If both **Assertion** and **Reason** are **correct** and Reason is the **correct explanation** of Assertion.
(b) If both **Assertion** and **Reason** are correct, but Reason is **not the correct explanation** of Assertion.
(c) If **Assertion** is **correct** but **Reason** is **incorrect**.
(d) If **Assertion** is **incorrect** but **Reason** is **correct**.

1. **Assertion :** There exists two angles of incidence for the same magnitude of deviation (except minimum deviation) by a prism kept in air.
   **Reason :** In a prism kept in air, a ray is incident on first surface and emerges out of second surface. Now if another ray is incident on second surface (of prism) along the previous emergent ray, then this ray emerges out of first surface along the previous incident ray. This particle is called principle of reversibility of light.
2. **Assertion :** Keeping a point object fixed, if a plane mirror is moved, the image will also move.
   **Reason :** In case of plane mirror, distance of object and its image is equal from any point on the mirror.
3. **Assertion :** The formula connecting $u$, $v$ and $f$ for a spherical mirror is valid for mirrors whose sizes are very small compared to their radii of curvature.
   **Reason :** Laws of reflection are strictly valid for plane surfaces, but not for large spherical surfaces.
4. **Assertion :** A lens having large aperture will produce image of a point source not as a point but as a diffused bright spot. This error of optical system is called spherical aberration.
   **Reason :** Paraxial rays are focused at a different point compared to marginal rays.
5. **Assertion :** A ray is incident from outside on a glass sphere surrounded by air as shown. This ray may suffer total internal reflection at second interface.




**Reason :** For a ray going from a denser to a rarer medium, the ray may suffer total internal reflection.

## MMQ Multiple Matching Questions :

**DIRECTIONS :** *Following question has four statements (A, B, C and D....) given in Column I and four statements (p, q, r and s.....) in Column II. Any given statement in Column I can have correct matching with one or more statement(s) given in Column II. Match the entries in column I with entries in column II.*

1.

| Column I | Column II |
|---|---|
| (A) Spectrometer | (p) refraction |
| (B) Mirrage | (q) deviation without dispersion |
| (C) Hollow prism | (r) to measure angle of prism |
| (D) Glass slab | (s) to measure the dispersion |

2.

| Column I | Column II |
|---|---|
| (A) Myopia | (p) convex lens |
| (B) Hyperopia | (q) concave lens |
| (C) Vivtual image | (r) plane mirror |
| (D) Magnification always one | (s) convex mirror |

3.

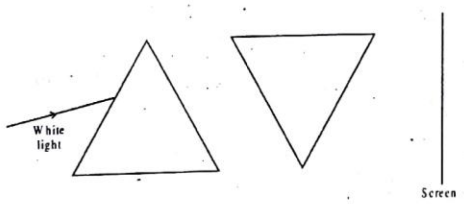
| Column I | Column II |
|---|---|
| (A) Plane mirror | (p) Primary colours |
| (B) Convex lens | (q) $4\pi$ steradian |
| (C) Spectroscope | (r) Incoherent scattering |
| (D) Atmospheric scattering of light | (s) Magnification always one |
| (E) RBG | (t) Refraction |
| (F) Optic fibre | (u) Burglar alarm |
| (G) Solid angle in a sphere | (v) Virtual and magnified image |
| (H) Photo electric effect | (w) Blue colour of effect the sky |
| (I) Raman effect | (x) Observing and studying spectrum |
| (J) Mirrage | (y) Total internal reflection |

Foundation Physics for class X Book 1 for IIT JEE standard 10 by Prof. K K Anand SmartEdu

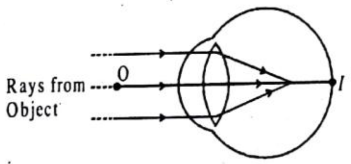
## HOTS Subjective Questions :

**DIRECTIONS :** *Answer the following questions.*

1. A person with a myopic eye cannot see objects beyond 1.2m distinctly. What should be the type of the corrective lens used to restore proper vision ?
2. The far point of a myopic person is 80 cm in front of the eye. What is the nature and power of lens required to correct the problem ?
3. A person cannot see objects nearer than 75 cm from his eyes while a person with normal vision can see objects upto 25 cm from his eyes. Find the nature, the focal length and the power of the correcting lens used for the defective vision.
4. A person can see clearly only up to 3 metres. Prescribe a lens for spectacles so that he can see clearly up to 12 metres. Defect is myopia.
5. The far point of a myopic person is 80 cm in front of the eye. What is the power of the lens required to enable him to see the distant objects clearly ?
6. A person with a defective eye-division is unable to see the objects nearer than 1.5m. He wants to read books at a distance of 30m. Find the nature, focal length and power of the lens he needs in his spectacles.
7. A ray of light is travelling in water medium falls on the water-air interface at an angle of 45° with the vertical. Will it be possible by the ray of light to come out of the water surface?
8. Complete the ray diagram (figure) to show the nature of light produced on the screen.

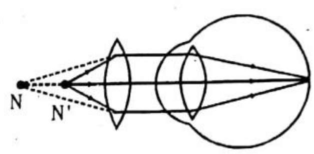



9. Study the figure given below and answer the questions that follow.




(a) Which defect of vision has been shown in the figure ?
(b) What do the points O and I represent ?
(c) Which lens is used to correct this defect ?
(d) Redraw the figure with the corrective lens.

10. In the diagram given below, a defective eye has been corrected. Study the diagram and answer the questions that follow.



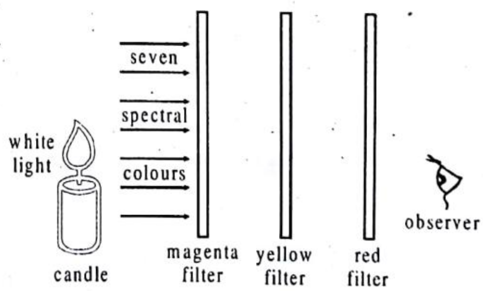

(a) Name the defect which has been corrected.

(b) Name the point N.

(c) Why a convex lens, instead of a concave lens, has been used ?

(d) Redraw the figure of the defective eye without the corrective lens.

11. The diagram given below shows the mechanism how stars twinkle due to atmospheric refraction. But there is something wrong with the drawing. Study the diagram carefully and predict the wrongness with it. Also redraw the correct diagram.
12. A watch-repairer has his near point at 20 cm. If he uses a magnifying glass of power 20 dioptre, what is the magnification that he gets?
13. One eye is sufficient to form the image of an object. What is the advantage of having two eyes ?
14. Although each eye perceives separated image, we do not see to thing in double with both eyes open. Why ?
15.




In the above diagram, extend the lines to show which of the seven spectral colours would pass through the magenta filter, the yellow filter and finally the red filter. Label the colour of each line.

16. How is presbyopia different from hypermetropia ?

# SOLUTIONS

*Brief Explanations of Selected Questions*

## Exercise 1

### Fill in the Blanks :

1. iris
2. pupil
3. retina
4. Rods
5. Cones
6. 25 cm.
7. near point
8. 25 cm to infinity
9. presbyopia.
10. astigmatism.
11. colour blindness
12. seven
13. dispersion
14. spectrum.
15. accommodation of the eye.
16. near point
17. myopia, hypermetropia, presbyopia.
18. dispersion.
19. Scattering of light
20. 7
21. $4 \times 10^{-7}$ m
22. $7 \times 10^{-7}$ m
23. incidence, equal, parallel

### True / False

1. False
2. True
3. True
4. True
5. False
6. True
7. True
8. True
9. True
10. True
11. False
12. False
13. True
14. True
15. True
16. False
17. True

### Match the Following :

1. (A) $\rightarrow$ s; (B) $\rightarrow$ r, p; (C) $\rightarrow$ q; (D) $\rightarrow$ q
2. (A) $\rightarrow$ q; (B) $\rightarrow$ p; (C) $\rightarrow$ r; (D) $\rightarrow$ s
3. (A) $\rightarrow$ s; (B) $\rightarrow$ u; (C) $\rightarrow$ x; (D) $\rightarrow$ w; (E) $\rightarrow$ p; (F) $\rightarrow$ y; (G) $\rightarrow$ q; (H) $\rightarrow$ u; (I) $\rightarrow$ r; (J) $\rightarrow$ t

### Very Short Answer Questions :

1. No, it will not show any dispersion but will show only deviation.
3. A pure spectrum is the one in which the colours are separated from one another using a narrow source of light.
4. Myopia.
5. Spherical aberration.
6. A rainbow is a natural spectrum appearing in the sky.
7. The ability of the eye to see objects at all distances is called accomodation
8. No, because there is no atmosphere in free space for refraction to take place.
9. Our arm describes a cone, and our finger sweeps out a circle. Likewise with rainbows.
10. No, as there won't be dispersion and total internal reflection.
11. The earth comes in the way of the rainbow and prevents it to form a complete circle.
12. The rainbow - colored fringe formed at the edges of a spot of white light coming from a beam of lantern or slide projector is due to diffraction of light rays coming from different part of the beam.
13. Back of the observer must be towards the sun.
14. No, this is because dispersion of light cannot occur on passing through air contained in a hollow prism.
15. This is because in the formation of a secondary rainbow, light enters from the bottom of the drop, instead of entering from the top as in case of primary rainbow and suffers two total internal reflections instead of one.
16. The statement is true, because a short-sighted person has difficulty in observing far off objects.
17. No, the statement is false. A hypermetropic person can observe far off objects without any problem.
18. This problem is due to astigmatism of the eye. This defect is removed using a cylindrical lens with appropriate axis and suitable radius of curvature.
19. $-0.5$ D
20. $f = -1$ m
21. True
22. Eye is the most developed sensory organ of a human being.
23. Cornea causes the first refraction.
24. Iris gives the characteristic colour of the eye.
25. Ciliary muscles can only compress or squeeze the crystalline lens to decrease its focal length; they cannot pull the lens to have larger focal length. Thus the power of accommodation is caused by the action of ciliary muscles.
26. Fovea is on the principal axis of the crystalline lens on the retina. Blind spot is a point on the retina where the optic nerve-fibres join together to form the optic nerve.
27. The size of the image increases as the object is brought nearer.
28. The distance of the watch from the eye must be such that its virtual image is formed at 30 cm from his eye.
29. Persistence of vision is the impression of an image on the retina for an instant after its withdrawal. Successive images produce an impression of continuity. This principle is used in cinema.

**SHORT ANSWER QUESTIONS :**

2. The crystalline lens of eye in older persons sometimes becomes milky and cloudy. This condition is called cataract. This causes partial or complete loss of vision.

3. Colour blindness is a defect of the eye due to which a person is unable to distinguish between certain colours, sometime even the primary colours.

4. The retina of human eye has a large number of light sensitive cells. These cells are of two types i.e., rod cells and cone cells. The rod shaped cells show response towards the intensity of light rays, while the cone shaped cells respond to colour. It is these cone cells, which make it possible for a man to see different colours and distinguish between them.

5. Focal length, f = – 50 cm (concave lens)
Now, Power,

$$P=\frac{1}{\text{f (in metre)}}=\frac{1}{-\frac{50}{100}\text{m}}=-\frac{100}{50}=-2$$

Thus, the power of this concave lens is –2 dioptres

6. **Fibre optic cables :** Fibre optic cables consisting of thousand glass fibres transmit thousands of telephonic conversations at the same time over long distances.

7. Different coloured rays deviate differently in the prism because the angle of refraction of different colours is different while passing through the glass prism.

8. The refractive index of diamond is very high. The faces of diamond are cut in such a way that the light entering into the diamond suffers total internal reflection repeatedly.

9. The continuously changing atmosphere causes refraction which is able to cause variation in the light coming from a point-sized star, thus the stars appear to be twinkling.

10. $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$ $v=-32$ cm, $f=8$ cm, $\therefore u=-32/5$

Now $m=v/u=5$

11. As here $u=-0.25$ m and $f=1/P=(1/3)$ m, from lens formula $P=\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$, we have $3=\frac{1}{v}-\frac{1}{-0.25}$

or $\frac{1}{v}=3-4=-1$ m

i.e. $v=-1$ m
i.e., the lens shifts the object from 25 cm to 1 m for clear vision, i.e., his near point is 1m. So in absence of glasses, he must hold the newspaper at a distance of 1m away from his eyes for clear vision.

12. In the bright sunlight, iris causes the pupil to become smaller so that only a small portion of light enters the eye and rods of the retina are also adjusted in the same way. But when a person enters into a dimly-lit room, each iris takes some time to increase the diameter of the pupil, so that more amount of light can enter the eyes to see the object clearly and rod cells of the retina also take some time to adjust themselves to get the picture of the object in the dim light.

13. A single raindrop illuminated by sunlight disperse the light to produce seven colors of the spectrum.
A viewer cannot see a full spectrum from a single raindrop because the colours of the spectrum formed by a single raindrop are separated by a large distance. A viewer sees the colours of a continuous spectrum dispersed by different raindrops. Millions of drops produce the entire spectrum of visible light.

14. All the rain drops that disperse the light to form rainbow lie within a cone of semi vertical angle 40° to 42°. If two observers are standing at a distance apart, they will observe rainbow at different parts on the surface of the cone. So the portion of the rainbow observed by an observer depends on the position of the observer. Two different observers will form two different cones with the observer standing at the vertex of the cone, therefore rainbows seen by them will be different.

15. Halos and seen around the moon are due to refraction of light by the crystals of ice in the atmosphere. Both rainbows and halos are seen in the form of arches.
The difference between rainbows and halos is that halos are formed due to refraction of light whereas rainbows are formed due to total internal reflection of light and refraction of light.

16. (a) The person is suffering from presbyopia.
(b) A bi-focal lens consists of both concave and convex lenses. The upper portion consists of a concave lens and the lower portion consists of a convex lens.

17. In a dark room or at very low level of illumination the supply of light sensitive chemicals in the rods of the retina increases to make the rods respond to that very low intensity of illumination; this takes half an hour to happen and this process is called dark adaptation.

18. For distant vision, defect is short sight
Focal length f = distance of defective far point = – 2m

$$\therefore P=-\frac{1}{2m}=-0.5 \text{ dioptre (concave)}$$

For near vision, u = normal distance of distinct vision = 0.25 m; v = defective near point = – 1 m (virtual image)

$$P=\frac{1}{f}=\frac{1}{v}-\frac{1}{u}=\frac{1}{-1}-\frac{1}{-0.25}$$

$$=-1+4=3 \text{ dioptre (convex)}$$

## LONG ANSWER QUESTIONS :

1. In the bright sunlight, iris causes the pupil to become smaller so that only a small portion of light enters the eye and rods of the retina are also adjusted in the same way. But when a person enters into a dimly-lit room, each iris takes some tome to increase the diameter of the pupil, so that more amount of light can enter the eyes to see the object clearly and rod cells of the retina also take some time to adjust themselves to get the picture of the object in the dim light.

2. Objective, eye piece
$m = m_o \times m_e = L/f_o \times D/f_e$
Ray diagram, find the values of L, fo, fe and obtain magnification ($m$).

3. Total internal reflection.

4. In a prism the refraction of light takes place at the two slant surfaces. The dispersion of white light occurs at the first surface of prism where its constituent colours are deviated through different angles. At the second surface, these split colours suffer only refraction and they get further separated. But in a rectangular glass block, the refraction of light takes place at the two parallel surfaces. At the first surface, although the white light splits into its constituent colours on refraction, but these split colours on suffering refraction at the second surface emerge out in form of a parallel beam, which give an impression of white light.

5. If a blackened bulb thermometer is moved from violet end towards the red end, first a steady rise in temperature is observed, but as the thermometer goes beyond the red end, there is rapid rise in temperature. This shows the existence of some kind of radiation producing the heating effect beyond the red end of the spectrum. If the radiations from the red end to the violet end are made to fall on the silver chloride solution, it almost remains unaffected beyond the violet end of the spectrum.

6. Yellow light is 'made up' of two of the primary colours, namely red and green. Hence, when this light is mixed with the light of the third primary colour, namely blue light, we get white light.
Yellow light + Blue light = (Red light + Green light) + Blue light = White light
The effect of mixing of two paints of different colours is not the same as that of mixing of two pure spectral lights. This is because each paint appears to have a colour that depends on the lights that it can reflect. Yellow paint is known to reflect red, green and yellow lights. Similarly blue paint reflects blue and green lights. Hence, when these two paints are mixed, the mixture can reflect only green light and thus appears green in colour.

7. We will have these observations if the given object is able to reflect red light but is not able to reflect blue light. This would be possible if the object is either of red or of yellow (= red + green) colour, as seen in normal day light. The red (or yellow) object would appear red when seen through a red glass because only the red light, reflected by it (from day light), passes through this glass. The red (or yellow) object would appear black when seen through a blue glass because none of the lights (red or red + green) reflected by it (from day light) passes through this glass.

8. If a blackened bulb thermometer is moved from violet end towards the red end, first a steady rise in temperature is observed, but as the thermometer goes beyond the red end, there is rapid rise in temperature. This shows existence of some kind of radiation producing the heating effect beyond the red end of the spectrum. If the radiations from the red end to the violet end are made to fall on the silver chloride solution, it almost remains unaffected beyond the violet end of the spectrum.

# Exercise 2

## MULTIPLE CHOICE QUESTIONS :

1. (a) 2. (d) 3. (c) 4. (c)

5. (c) Dispersive power of prism $\omega = \left(\frac{\mu_v - \mu_r}{\mu_y - 1}\right)$

$$\text{but } \mu_y = \frac{\mu_v + \mu_r}{2} = \frac{1.52 + 1.51}{2} = 1.515$$

$$\text{Therefore } \omega = \frac{1.52 - 1.51}{1.515 - 1} = \frac{0.1}{1.515} = 0.019.$$

6. (b) $\mu = \frac{\sin(A + \delta_m)/2}{\sin 30^\circ}$

$$\Rightarrow 1.414 = \frac{\sin(60 + \delta_m)/2}{\sin 30^\circ}$$

$$\Rightarrow \text{Sin}\left(\frac{60^\circ + \delta_m}{2}\right) = 0.707 = \sin 45^\circ$$

$$\Rightarrow \frac{60 + \delta_m}{2} = 45^\circ \Rightarrow \delta_m = 30^\circ$$

7. (c) $M = -\frac{f_0}{f_e} = -\frac{400}{10} = -40$

Angle subtended by the moon at the objective

$$= \frac{3.5 \times 10^3}{3.8 \times 10^5} = 0.009 \text{ radian.}$$

Thus angular diameter of the image
$= M \times$ visual angle
$= 40 \times 0.009 = 0.36$ radian

$$= \frac{0.36 \times 180}{3.14} = 20^\circ$$

**8.** (b) $m = \frac{f_0}{f_e} = \frac{\beta}{\alpha}$

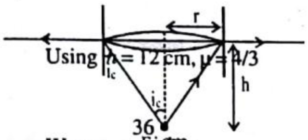
$\therefore \quad \beta = \alpha \frac{f_0}{f_e} = 2 \times \frac{60}{5} = 24°$

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **9.** | (d) | **10.** | (a) | **11.** | (d) | **12.** | (d) |
| **13.** | (b) | **14.** | (c) | | | | |

**15.** (a) Disperssion arises because of basic phenomenon refraction.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **16.** | (d) | **17.** | (a) | **18.** | (b) | **19.** | (c) |
| **20.** | (b) | **21.** | (b) | **22.** | (a) | **23.** | (d) |

**24.** (d) $\sin i_c = \frac{1}{\mu} = \frac{r}{\sqrt{r^2 + h^2}}$




Using h = 12 cm, $\mu = 4/3$

We get $\frac{36}{\sqrt{7}}$ cm.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **25.** | (c) | **26.** | (d) | **27.** | (b) | **28.** | (c) |
| **29.** | (b) | **30.** | (d) | **31.** | (a) | **32.** | (c) |
| **33.** | (c) | **34.** | (a) | **35.** | (c) | **36.** | (b) |
| **37.** | (a) | **38.** | (c) | **39.** | (b) | **40.** | (c) |
| **41.** | (b) | **42.** | (c) | **43.** | (a) | **44.** | (a) |
| **45.** | (b) | **46.** | (c) | **47.** | (b) | **48.** | (a) |
| **49.** | (a) | **50.** | (c) | **51.** | (c) | **52.** | (d) |
| **53.** | (d) | **54.** | (c) | **55.** | (c) | **56.** | (c) |
| **57.** | (d) | **58.** | (a) | **59.** | (d) | **60.** | (a) |
| **61.** | (c) | **62.** | (d) | **63.** | (c) | | |
| **64.** | (d) $i = 2r$ | **65.** | (d) | | | | |

## MORE THAN ONE CORRECT :

| | | | | | |
|---|---|---|---|---|---|
| **1.** | (a,c,d) | **2.** | (a,b,d) | **3.** | (b,c,d) |
| **4.** | (a,b,c) | **5.** | (a,b,c) | **6.** | (b) |
| **7** | (a,c,d) | **8.** | (a.b,c) | **9.** | (b,c) |
| **10.** | (all) | **11.** | (a,b,) | **12.** | (b,c,d) |
| **13.** | (b,c,d) | **14.** | (a,b,c) | **15.** | (a,b,d) |
| **12.** | (a,b,c) | | | | |

## FILL IN THE PASSAGE :

**I** (1) myopia
(2) distant
(3) infront of
(4) concave

**II** (1) critical
(2) total internal reflection
(3) denser
(4) rarer
(5) mirage

## PASSAGE BASED QUESTIONS :

**Passage: I**

**1.** (a) **2.** (b) **3.** (a)

$m_1 = \frac{f}{-u_1 + f} = -6 \Rightarrow u_1 = \frac{7}{6} f$

$m_2 = \frac{f}{-u_2 + f} = -2 \Rightarrow u_2 = \frac{3}{2} f$

$u_2 - u_1 = \left(\frac{7}{6} - \frac{3}{2}\right) f = -\frac{2}{6} f = -\frac{1}{3} f = -12$ cm.

$\Rightarrow f = 36$ cm.

$u_1 = \frac{7}{6} \times 36 \text{ cm} = 42 \text{ cm}$

$u_2 = \frac{3}{2} \times 36 \text{ cm} = 54 \text{ cm}$

$m_3 = \frac{f}{-u_3 + f} = -\frac{1}{4} \Rightarrow u_3 = 5f$

$u_3 = 5 \times 36 \text{ cm} = 180$ cm.

**Passage: II**

**4.** (d) **5.** (b) **6.** (b)

$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$

Here v = 2.5 (Distance of retina as position of image is fixed)

$u = -x$

$\frac{1}{f} = \frac{1}{2.5} + \frac{1}{x}$

For $f_{min}$ : x is minimum $\frac{1}{f_{min}} = \frac{1}{2.5} + \frac{1}{25}$

For $f_{max}$ : x is maximum $\frac{1}{f_{max}} = \frac{1}{2.5} + \frac{1}{\infty}$

For near sighted man lens should make the image of the object within 100 cm range

For lens $u = -\infty$, $v = -100$

$$\frac{1}{f_{lens}} = \frac{1}{-100} - \frac{1}{-\infty}$$

**Passage: III**

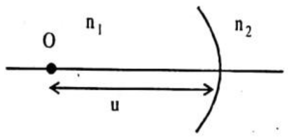
**7.** (b) **8.** (d) **9.** (d).

$$\frac{\mu_2}{v} = \frac{\mu_1}{u} + \left(\frac{\mu_2 - \mu_1}{R}\right)$$

$(\mu_2 - \mu_1)$ is +ve and R is –ve, if u is –ve, v will always be –ve.

i.e. for real object image is always virtual.

Consider object on left side of spherical surface seperating two media. If real object is in rarer media i.e. $n_1 < n_2$




Then, $\frac{n_2}{v} = \frac{n_2 - n_1}{(-u)} + \frac{n_1}{(-R)} = -ve$

Hence image shall be virtual for a real object lying on concave side with rare media. ..........(1)

If real object is in denser media i.e., $n_1 > n_2$

$$\frac{n_2}{v} = \frac{-(n_1 - n_2)}{(-u)} + \frac{n_1}{(-R)} = \frac{n_1 - n_2}{u} - \frac{n_1}{R}$$

$\therefore$ Image is real if $\frac{n_1 - n_2}{u} > \frac{n_1}{R}$

or $u < \frac{(n_1 - n_2)R}{n_1}$ ..........(2)

and image is virtual if $u > \left(\frac{n_1 - n_2}{n_1}\right)R$ ..........(3)

From statements 1, 2 and 3 we can easily conclude the answers.

## ASSERTION & REASON :

1. (a) Reason is correct explanation of Assertion.
2. (d) If the mirror is shifted parallel to itself such that the velocity of the mirror is parallel to its surface, the image shall not shift. Hence statement 1 is false.
3. (c) Assertion : The mirror (spherical) formula $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$ is valid only for mirrors of small apertures where the size of aperture is very small as compared to the radius of curvature of the mirror. This statement is true.
   Reason : Laws of mirror are valid for plane as well as large spherical surfaces.
   Therefore, statement 2 is wrong.
4. (a) The formula $\frac{1}{f} = (\mu - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$ is valid for a lens of small aperture. So paraxial and marginal rays focus at different points.
5. (d) From symmetry the ray shall not suffer TIR at second interface, because the angle of incidence at first interface equals to angle of emergence at second interface. Hence Assertion is false.

## MULTIPLE MATCHING QUESTIONS :

1. (A) $\rightarrow$ s, r; (B) $\rightarrow$ r, p; (C) $\rightarrow$ q; (D) $\rightarrow$ q
2. (A) $\rightarrow$ q,r ; (B) $\rightarrow$ p; (C) $\rightarrow$ s, r; (D) $\rightarrow$ r
3. (A) $\rightarrow$ s; (B) $\rightarrow$ v; (C) $\rightarrow$ x; (D) $\rightarrow$ w; (E) $\rightarrow$ p; (F) $\rightarrow$ y; (G) $\rightarrow$ q; (H) $\rightarrow$ u; (I) $\rightarrow$ r; (J) $\rightarrow$ t, y

## HOTS SUBJECTIVE QUESTIONS :

**1.** In normal eye, the far point is infinity. The lens used should be such that an object at infinity forms virtual image at 1.2 m.

Now, $v = -1.2$ m; $v = -\infty, f = ?$

We know $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$

or $\frac{1}{f} = \frac{1}{-1.2} - \frac{1}{(-\infty)} = -\frac{1}{1.2}$ or $f = -1.2$ m

Power, $P = \frac{1}{f} = \frac{1}{-1.2} = \frac{-5}{6} = -0.83\ D$

A concave (or divergent) lens of focal length 1.2 m and power – 0.83 D should be used to restore proper vision.

**2.** The far point of this myopic person is 80 cm. This means that this person can see the distant object (which is kept at infinity) clearly if the image of this object is formed at his far point (80 cm). Therefore, in this case,

$$u = -\infty,\ v = -80\ cm,\ f = ?$$

Using lens formula, $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$

or $\frac{1}{-80}-\frac{1}{\infty}=\frac{1}{f}$ or $-\frac{1}{80}-0=\frac{1}{f}$

or $f=-80\text{ cm}=-0.8\text{ m}$

The negative (–) sign indicates that the lens is concave.

Now, Power $P=\frac{1}{f\ (in\ m)}=\frac{1}{-0.8}=-1.25\ D$

The concave lens of power – 1.25 D is required to correct the problem.

3. The defect of the vision is hypermetropia. The formula used is $\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$

Given, $u=-25$ cm and $v=-75$ cm.

$\therefore\ \frac{1}{f}=-\frac{1}{75}+\frac{1}{25}=+\frac{2}{75}$ or $f=+\frac{75}{2}=+37.5$ cm

Power of the lens

$=\frac{1}{f\ (\text{in metres})}=\frac{100}{75/2}=+\frac{8}{3}=+2.67\ D$

4. Here, $v=-3$ m, $u=-12$ m, $f=?$

$\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$ or $-\frac{1}{3}+\frac{1}{12}=\frac{1}{f}$ or $f=-4$ m

A concave lens of focal length 4 m should be used.

5. A myopic person needs a concave lens for the correction of his eyesight.

His $v=-80$ cm. (far point), $u=\infty$ (infinity)

So, $\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$ $\quad\frac{1}{f}=\frac{1}{v}$ $\left(\text{as }\frac{1}{\infty}=0\right)$

$\Rightarrow\ \frac{1}{f}=\frac{1}{-80}\ \Rightarrow\ f=-80\text{ cm}\ \Rightarrow f=-0.8$ m.

$\therefore\ P=\frac{1}{-0.8}=-1.25\ D$ (Dioptres)

6. This person is hypermetropic

So, his $u=-30$ cm, $v=-1.5\text{ m}=-150$ cm

Focal length of corrective lens :

$\frac{1}{f}=\frac{1}{v}-\frac{1}{u}\ \Rightarrow\ \frac{1}{f}=\frac{1}{-150}-\frac{1}{-30}\ \Rightarrow\ \frac{1}{f}=\frac{-1}{150}+\frac{1}{30}$

$\Rightarrow\ \frac{1}{f}=\frac{-1+5}{150}=\frac{4}{150}\ \Rightarrow f=\frac{150}{4}=+37.5$ cm

+ sign shows that he needs a convex lens of focal length 37.5 cm.

$\therefore$ Power of lens (P) $=\frac{100}{37.5}=2.67$ D

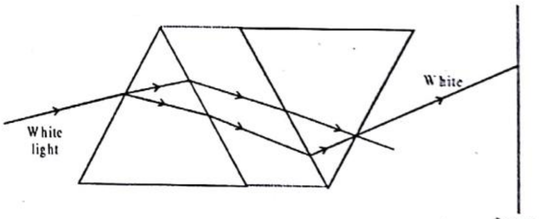
7. From the relationship between critical angle ($i_c$) and refractive index ($\mu$), we get $\sin i_c=\frac{1}{\mu}$

In the case of water, $\mu=1.33$

so, $\sin i_c=\frac{1}{1.33}$ or $i_c=48°$

But, the angle of resistance is 45° i.e. $i=45°$ and $i_c>i$. If the angle of incidence would have been greater than the critical angle, then the ray of light might not come out of water surface due to total internal reflection. But in the present situation, since the angle of incidence is less than the critical angle, the ray of light will be able to come out of the water surface.

8. The light on the screen is white with faint colour at the edges.



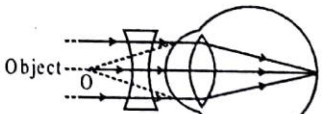

This is because the dispersion caused by the first prism is compensated by the second prism. The emergent beam is parallel to the incident beam. The two prisms together behave like a glass block with parallel sides.

9. (a) Myopia or near-sightedness has been shown in the figure.

(b) The points $O$ and $I$ represent the far point and the retina respectively.

(c) A concave lens of proper focal length is used to correct this defect.

(d)




Correctness for myopia

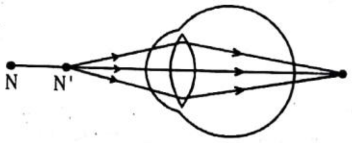
**10.** (a) Hypermetropia or long-sightedness has been corrected.

(b) The point represent the near point of the hypermetropic eye.

(c) In a hypermetropic eye, the rays of light coming from a near object don't converge in appropriate way so as to focus at retina but they get focussed beyond the retina. When a convex lens is used before the eye, extra focussing power is provided and the rays are focussed at the retina.

If a concave lens, on the other hand, will be used then it will diverge the rays and they will get focussed at a point more beyond the retina.

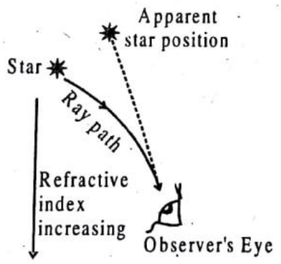
(d)




Hypermetropic eye

**11.** Twinkling of stars takes place as a result of atmospheric refraction. The starlight, on entering the earth's atmosphere, undergoes refraction at its different layers. The refractive index of the atmosphere gradually increases downwards. But in the diagram it has been shown to decrease. This is what is wrong with the diagram.

The correct diagram is given below.




**12.** $P = 20\,D,\ f = \frac{1}{20} = 0.05$ m

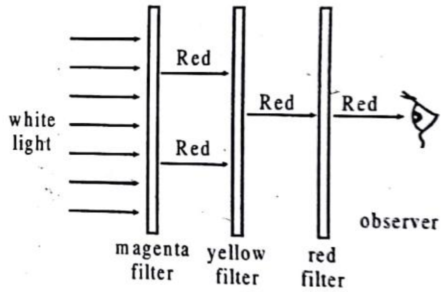
$m = 1 - \frac{v}{f};\ v = -20 \text{ cm} = 0.2$ m

$\therefore\ m = 1 + \frac{0.2}{0.05} = 1 + 4 = 5$

**13.** The area seen clearly with one eye is comparatively less than that seen with two eyes. Further two eyes give better judgement of distances of distant objects than one eye only. Also, left eye sees more portion of the right side of the object and the right eye sees more of the left side. Thus, two eyes do not form exactly similar images and the fusion of these two dissimilar images in the brain gives the three dimensional or the stereoscopic vision.

**14.** The axes of the two eyes are directed towards the same object. Therefore there appears to be only one object. The two separate images formed by the two eyes get fused in the brain. The optic nerves lead to the same point in the brain producing only one sensation. Hence, we see only one object with two eyes.

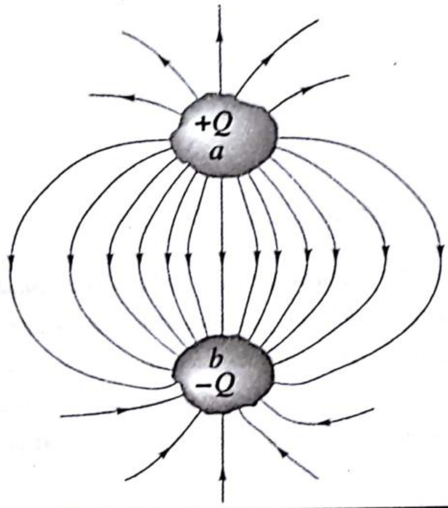
**15.**




**16.** Presbyopia is a defect only for near vision due to insufficient power of accommodation arising out of the inability of the ciliary muscles to squeeze the crystalline lens beyond a particular power i.e., to the full extent as in a normal defectless eye, so the near point is beyond 25 cm, whereas the far point in the relaxed condition of the eye is at infinity.

In a hypermetropic eye the crystalline lens has become less powerful (in the relaxed condition) and so it has to exercise power of accommodation to see infinitely distant objects also straining the ciliary muscles. Hypermetropia is the defect for near vision.

chapter 3




# STATIC ELECTRICITY

## Introduction

Electricity is the cause of something present in matters called the 'electric charge'. Although charges are present in all matters but all of them do not produce electricity. Actually, electricity is produced by those matters which are 'electrically charged' or by charges in motion. The electricity produced by charges at rest is known as static electricity and the electricity produced by charges in motion is called 'current electricity'.

This chapter deals with the electricity produced by charges at rest. A static charge can produce an electric field but it can't produce an electric current. Electric current can be produced only when the charges are in motion which is the subject matter of the next chapter. Electric charges can be stored and used as per requirement. The device which stores charges is known as 'capacitor' to be dealt with in this chapter.

**Electric charge**

We know that mass is responsible of gravitational force. Similarly, there is a property to every massive object which is responsible for another kind of force which can be attractive or repulsive unlike gravitational force which is only attractive. Also, this force is much more stronger than gravitational forces. This force is termed as electrical force. So, charge is responsible for electrical forces.

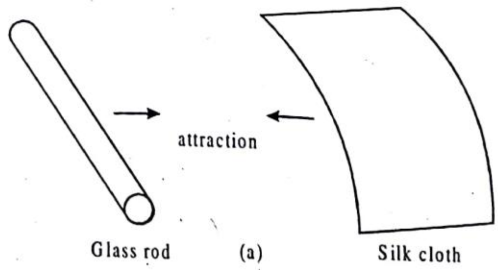
*Electric eels can generate an electrical charge of up to 600 volts in order to stun prey and keep predators at bay. Up to 6,000 electroplates are arranged like a dry cell in the eel's body. Its internal organs are all in a small area behind the head, with 7/8 of the eel being tail. The electrical shocks come from muscles mainly in the tail portion of the electric eel's body. The body of an electric eel is similar to a battery.*

*The tail end of the eel has a positive charge and the head region is negatively charged. When the eel touches its tail and head to other animals it sends electric shocks through their bodies. When the eel is at rest, there is no generation of electrical impulses.*

*Fig. 3.1 : Electric eel*

## HISTORICAL PREVIEW

It was discovered centuries ago that certain types of materials would mysteriously attract one another after being rubbed together. For example: after rubbing a piece of silk against a piece of glass, the silk and glass would tend to stick together. Indeed, there was an attractive force that could be demonstrated even when the two materials were separated:




Glass and silk aren't the only materials known to behave like this. Anyone who has ever brushed up against a latex balloon only to find that it tries to stick to them has experienced this same phenomenon. Paraffin wax and wool cloth are another pair of materials early experimenters recognized as manifesting attractive forces after being rubbed together.

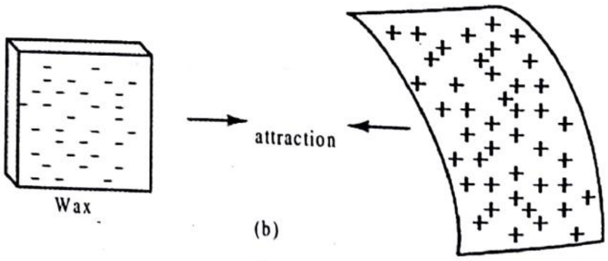



*Fig. 3.2*

This phenomenon became even more interesting when it was discovered that identical materials, after having been rubbed with their respective cloths, always repelled each other:

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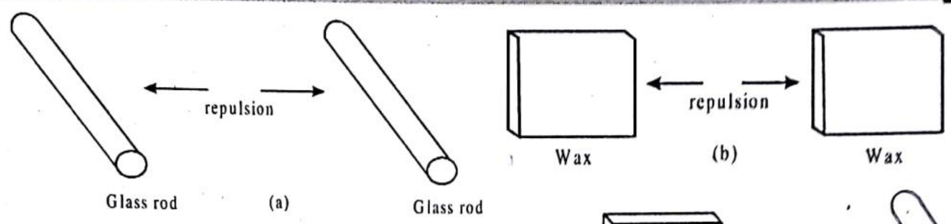



It was also noted that when a piece of glass rubbed with silk was exposed to a piece of wax rubbed with wool, the two materials would attract one another:

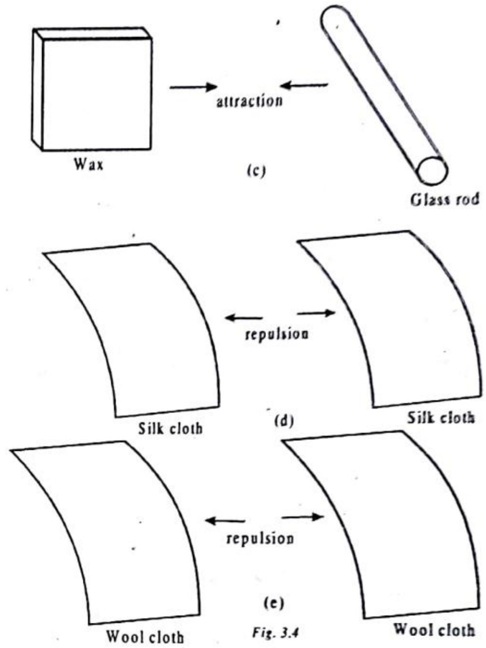



Fig. 3.4

Furthermore, it was found that any material demonstrating properties of attraction or repulsion after being rubbed could be classed into one of two distinct categories: attracted to glass and repelled by wax, or repelled by glass and attracted to wax. It was either one or the other: there were no materials found that would be attracted to or repelled by both glass and wax, or that reacted to one without reacting to the other.

More attention was directed toward the pieces of cloth used to do the rubbing. It was discovered that after rubbing two pieces of glass with two pieces of silk cloth, not only did the glass pieces repel each other, but so did the cloths. The same phenomenon held for the pieces of wool used to rub the wax:

Now, this was really strange to witness. After all, none of these objects were visibly altered by the rubbing, yet they definitely behaved differently than before they were rubbed. Whatever change took place to make these materials attract or repel one another was invisible.

Some experimenters speculated that invisible "fluids" were being transferred from one object to another during the process of rubbing, and that these "fluids" were able to effect a physical force over a distance. Charles Dufay was one the early experimenters who demonstrated that there were definitely two different types of changes brought by rubbing certain pairs of objects together. The fact that there was more than one type of change manifested in these materials was evident by the fact that there were two types of forces produced: attraction and repulsion. The hypothetical fluid transfer became known as a charge.

One pioneering researcher, Benjamin Franklin, came to the conclusion that there was only one fluid exchanged between rubbed objects, and that the two different "charges" were nothing more than either an excess or a deficiency of that one fluid. After experimenting with wax and wool, Franklin suggested that the coarse wool removed some of this invisible fluid from the smooth wax, causing an excess of fluid on the wool and a deficiency of fluid on the wax. The resulting disparity in fluid content between the wool and wax would then cause an attractive force, as the fluid tried to regain its former balance between the two materials.

Postulating the existence of a single "fluid" that was either gained or lost through rubbing accounted best for the observed behavior: that all these materials fell neatly into one of two categories when rubbed, and most importantly, that the two active materials rubbed against each other always fell into opposing categories as evidenced by their invariable attraction to one another. In other words, there was never a time where two materials rubbed against each other both became either positive or negative.

Following Franklin's speculation of the wool rubbing something off of the wax, the type of charge that was associated with rubbed wax became known as "negative" (because it was supposed to have a deficiency of fluid) while the type of charge associated with the rubbing wool became known as "positive" (because it was supposed to have an excess of fluid). Little did he know that his innocent conjecture would cause much confusion for students of electricity in the future.

Precise measurements of electrical charge were carried out by the French physicist Charles Coulomb in the 1780's using a device called a torsional balance measuring the force generated between two electrically charged objects. The results of Coulomb's work led to the development of a unit of electrical charge named in his honor, the coulomb. If two "point" objects (hypothetical objects having no appreciable surface area) were equally charged to a measure of 1 coulomb, and placed 1 meter (approximately 1 yard) apart, they would generate a force of about 9 billion newtons (approximately 2 billion pounds), either attracting or repelling depending on the types of charges involved.

It was discovered much later that this "fluid" was actually composed of extremely small bits of matter called electrons, so named in honour of the ancient Greek word for amber: another material exhibiting charged properties when rubbed with cloth. Experimentation has since revealed that all objects are composed of extremely small "building-blocks" known as atoms, and that these atoms are in turn composed of smaller components known as particles. The three fundamental particles comprising atoms are called protons, neutrons, and electrons.

The result of an imbalance of this "fluid" (electrons) between objects is called static electricity. It is called "static" because the displaced electrons tend to remain stationary after being moved from one material to another.

**Activity :** Take any two materials from the following list and then rubbed with each other. We can always find that the former one is positively charged and the later one is negatively charged.

Fur $\rightarrow$ glass $\rightarrow$ paper $\rightarrow$ metal $\rightarrow$ silk $\rightarrow$ plastic $\rightarrow$ amber $\rightarrow$ rubber $\rightarrow$ sulfur

When a charged body is close enough to a neutral body, they attract each other. One of the applications of this effect is to use tiny paint droplets to paint the automobiles uniformly.

## CHECK Point

**When one material is rubbed against another, electrons jump readily from one to the other, but protons do not. Why is this? (Think in atomic terms.)**

**SOLUTION**

Protons are bound with the nucleus of an atom but electrons revolve round it. Therefore, electrons can easily be dislodged from an atom but it is difficult to take out a proton from the atom. This is why, when one material is rubbed against another, electrons jump readily from one to the other, but protons do not.

## PROPERTIES OF CHARGES :

1. **Charge is conserved**
   That is, net charge can neither be created nor destroyed. Note the term net charge. Although charges can be created or destroyed in some processes but the net charge always remains conserved.
2. **Charge is quantized**
   Charge on any particle can never be less than the charge of an electron (i.e., $e = -1.6 \times 10^{-19}\ C$).
   In other words, the total charge on any particle is an integral multiple of the charge of electron ($e$). Let a particle has charge $Q$ then
   $$q = \pm ne, \quad \text{where } n = 1, 2, 3, 4, \ldots\ldots$$
   It means that a charge of $\frac{2}{3}e, \frac{1}{4}e$ or $\frac{4}{5}e$ on any body is not possible as they are not integral multiple of the charge of electron.
3. Unlike charges repel each other and like charges attract each other.
4. A charge at rest produces an electric field in the space around it. A uniformly moving charge produces both electric and magnetic field and a non-uniformly moving charge radiates energy.

### ILLUSTRATION–3.1

Calculate the net charge on a substance consisting of (a) $5 \times 10^{14}$ electrons (b) a combination of $7 \times 10^{13}$ protons and $4 \times 10^{13}$ electrons.

**SOLUTION :**

(a) The charge of one electron is $-1.6 \times 10^{-19} C$. So net charge on a substance consisting of $5 \times 10^{14}$ electrons is
$5 \times 10^{14} \times (-1.6 \times 10^{-19} C) = -8 \times 10^{-5} C = -80 \mu C.$

(b) Similarly the net charge on a substance consisting of a combination of $7 \times 10^{13}$ protons and $4 \times 10^{13}$ electron is
$[7 \times 10^{13} \times (1.6 \times 10^{-19} C)] + [4 \times 10^{13} (-1.6 \times 10^{-19} - C]$
$= +4.8\ \mu C.$
($\because$ the charge on one proton is $+ 1.6 \times 10^{19}$)

**ILLUSTRATION 3.2**

When a piece of polythene is rubbed with wool, a charge of $-2 \times 10^{-7}$ $C$ is developed on polythene. What is the amount of mass, which is transferred to polythene?

**SOLUTION:**

No. of electrons transferred, $n = \frac{q}{e}$

Mass transferred $= m_e \times n = m_e \times \left(\frac{q}{e}\right)$

$$= 9.1 \times 10^{-31} \times \left(\frac{2 \times 10^{-7}}{1.6 \times 10^{-19}}\right)$$

$$= 11.38 \times 10^{-19} \text{ kg}$$

## CONDUCTORS AND INSULATORS

Suppose you charge a rubber rod and then touch it to a neutral object. Some charge, repelled by the negative charge on the rod, will be transferred to the originally-neutral object. What happens to that charge then depends on the material of which the originally-neutral object consists. In the case of some materials, the charge will stay on the spot where the originally neutral object is touched by the charged rod. Such materials are referred to as insulators, materials through which charge cannot move, or, through which the movement of charge is very limited. Examples of good insulators are quartz, glass, and air. In the case of other materials, the charge, almost instantly spreads out all over the material, in response to the force of repulsion (recalling that force causes acceleration which leads to the movement) that each elementary particle of the charge exerts on every other elementary particle of charge. Materials in which the charge is free to move about are referred to as conductors. Examples of good conductors are metals and saltwater.

When you put some charge on a conductor, it immediately spreads out all over the conductor. The larger the conductor, the more it spreads out. In the case of a very large object, the charge can spread out so much that any chunk of the object has a negligible amount of charge and hence, behaves as if were neutral. Near the surface of the earth, the earth itself is large enough to play such a role. If we bury a good conductor such as a long copper rod or pipe, in the earth, and connect to it another good conductor such as a copper wire, which we might connect to another metal object, such as a cover plate for an electrical socket, above but near the surface of the earth, we can take advantage of the earth's nature as a huge object made largely of conducting material. If we touch a charged rubber rod to the metal cover plate just mentioned, and then withdraw the rod, the charge that is transferred to the metal plate spreads out over the earth to the extent that the cover plate is neutral. We use the expression "the charge that was transferred to the cover plate has flowed into the earth." A conductor that is connected to the earth in the manner that the cover plate just discussed is connected is called "ground." The act of touching a charged object to ground is referred to as grounding the object. If the object itself is a conductor, grounding it (in the absence of other charged objects) causes it to become neutral.

## CHARGING BY INDUCTION

When a charged particle is taken near to neutral metallic object then the electrons move to one side and there is excess of electrons on that side making it negatively charged and deficiency on the other side making that side positively charged. Hence charges appear on two sides of the body (although total charge of the body is still zero). This phenomenon is called induction and the charge produced by it is called induced charge.

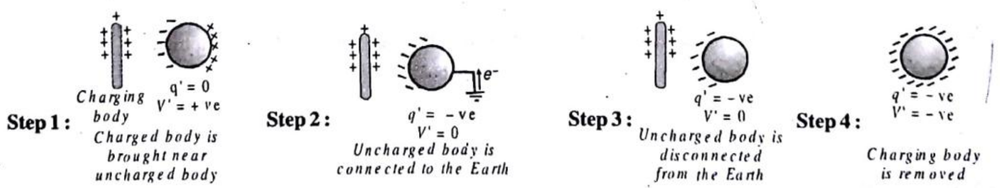



*Fig. 3.5*

A body can be charged by means of (a) friction, (b) conduction, (c) induction, (d) thermoionic ionisation, (e) photoelectric effect and (f) field emission.

## COULOMB'S LAW

The force exerted by one point charge on another acts along the line joining the two charges. It varies inversely as the square of the distance separating the charges and is proportional to the product of the charges. The force depends on the medium. The force is repulsive if the charges have the same sign and attractive if the charges have opposite signs.

The magnitude of the electric force exerted by a charge $q_1$ on another charge $q_2$ a distance $r$ away is thus given by :

$$F = \frac{k|q_1q_2|}{r^2}$$

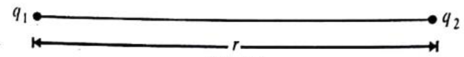



Fig. 3.6

Where $k$ is an experimentally determined constant called the Coulomb constant, which has the value

$$k = 8.99 \times 10^9\ \mathrm{N.m^2/C^2}$$

If $q_1$ is at position $\vec{r}_1$ and $q_2$ is at $\vec{r}_2$, the force $\vec{F}_{1,2}$ exerted by $q_1$ on $q_2$ is

$$\vec{F}_{1,2} = \frac{kq_1q_2}{r_{1,2}^2}\hat{r}_{1,2}$$

Where $\vec{r}_{1,2} = \vec{r}_2 - \vec{r}_1$ is the vector pointing from $q_1$ to $q_2$, and $\hat{r}_{1,2} = \vec{r}_{1,2}/r_{1,2}$ is a unit vector pointing from $q_1$ to $q_2$.

It is common practice to express $k$ in terms of another constant $\varepsilon_0$, by writing $k = 1/(4\pi\varepsilon_0)$; $\varepsilon_0$ is called the permittivity of free space and has a value of $\varepsilon_0 = 1/(4\pi k) = 8.85 \times 10^{-12}\ \mathrm{C^2/(N/m^2)}$. i.e. per mission of activity between charge depends on medium.

If some dielectric (insulator) is present in the space between the charges, the net force acting on each charge is altered. The force decreases $k$ times if the medium extends till infinity. Here $k$ is a dimensionless constant which depends on the medium and called dielectric constant of the medium. Thus

$$F_e = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q_1q_2}{r_2} \quad \text{or} \quad F_e' = \frac{F_e}{k} = \frac{1}{4\pi\varepsilon_0 k}\cdot\frac{q_1q_2}{r_2} = \frac{1}{4\pi\varepsilon}\cdot\frac{q_1q_2}{r^2}$$

Here, $\varepsilon = \varepsilon_0 k$ is called permittivity of the medium.

For vacuum or air $K = 1$, For water $k = 80$, For Mica $k = 7$ to $10$

## CHECK Point

- **How does the magnitude of electric force compare with the charge between a pair of charged particles when they are brought to half their original distance of separation? To one-quarter their original distance? To four times their original distance? (What law guides your answers?)**

### SOLUTION

According to inverse-square law, the electric force between two charges is inversely proportional to the square of the distance of their separation. Therefore, when the charges are brought to half their original distance of separation, the electric force between them increases by four times.

If the separation distance is made one-quarter their original distance, the force increases by sixteen times.

Similarly, the force between the charges decreases by sixteen times when the separation distance between them is made four times their original distance.

(The inverse square law guides our answer).

## ILLUSTRATION 3.3

Three identical point charges are placed at the corners of an equilateral triangle. If the electrostatic force between the any tow charges is $F$, then find the net electrostatic force on the each one.

**SOLUTION:**

Three identical points charges, say, positive and having magnitude $q$, are placed at the corners of an equilateral triangle, as shown. The charge at the top corner experiences two electrostatic repulsive forces $F$, $F$ due to the other two charges. Then, the net electrostatic force on this charge becomes

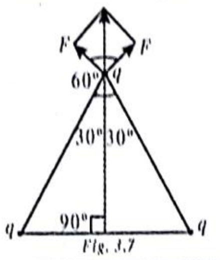



Fig. 3.7

$$F' = \sqrt{F^2 + F^2 + 2F \times F \cos 60°}$$
$$= F\sqrt{3}$$

and acts in direction perpendicular to the base of triangle, as shown.

**ILLUSTRATION 3.4**

Tow points charges $q_1 = +2C$ and $q_2 = -1C$ are separated by a distance $r$. Then, define the position of a third point charge $q_3 = +1C$ in the equilibrium on the line passing through the two charges.

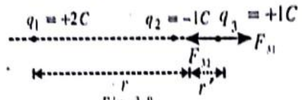



Fig. 3.8

**SOLUTION:**

The third charge $q_3$ must be situated on the line passing through the two charges $q_1$ and $q_2$, as shown. This charge experiences a repulsive electrostatic force $F_{31}$ due to $q_1$ and an attractive electrostatic force $F_{32}$ due to $q_2$. The forces $F_{31}$ and $F_{32}$ are equal but opposite so that the net electrostatic force on the charge $q_3$ is zero and hence, it is in the equilibrium.

$$F_{31} = F_{32}$$

$$\Rightarrow \quad \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{2\times1}{(r+r')^2} = \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{1\times1}{(r')^2}$$

$$\Rightarrow \quad r + r' = \sqrt{2}r'$$

$$\Rightarrow \quad r' = \frac{r}{(\sqrt{2}-1)}$$

which is the distance of $q_3$ from $q_2$.

**ILLUSTRATION 3.5**

Electric force between two point charges $q$ and $Q$ at rest is $F$. Now if a charge $-q$ is placed next to $q$ what will be the (a) force on $Q$ due to $q$ (b) total force on $Q$ ?

**SOLUTION:**

(a) As electric force between two body interaction, i.e., force between two particles, is independent of presence or absence of other particles, the force between $Q$ and $q$ will remain unchanged, i.e., $F$.

(b) An electric force is proportional to the magnitude of charges, total force on Q will be given by :

$$\frac{F'}{F} = \frac{Qq'}{Qq} = \frac{q'}{q} = \frac{0}{q} = 0 \quad [\text{as } q' = q + (-q) = 0]$$

i.e., The resultant force on $Q$ will be zero.

## ELECTRIC FIELD

If we place a charge in any region of space, it is observed that any other charge placed in that region experiences a force. The space around an electric charge is filled with a field called electric field.

The **intensity of electric field** is a vector quantity which at a point, is defined as the force experienced by a unit positive charge placed at that point. Its direction is in the direction of the electric field if the charge is positive and opposite to it if the charge is negative. Mathematically,

$$E = \frac{F}{q}, \text{ where } E = \text{electric field; } F = \text{force experienced by charge } q.$$

The unit of electric field is newton per coulomb (N/C).

**ILLUSTRATION – 3.6**

A particle of mass $m$ and charge $+q$ is placed at rest in a uniform electric field $\vec{E}$, as a shown, and released. Calculate the kinetic energy it gains after moving a distance $h$.

**SOLUTION:**

The particle experiences an electric force of magnitude

$$F = qE$$

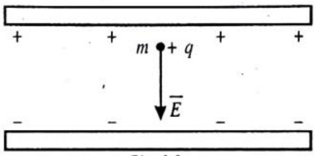



Fig. 3.9

in the downward direction. This force does a positive work

$W = F \times h = qEh$

on the particle and the particle gains a kinetic energy equal to this work done, when it is released in the electric field and moves downwards through the distance $h$ due to the electric force on it.

## Knowledge ENHANCER

**Electric field due to Single Point Charge**

The electric field $\vec{E}$ at a point $P$ at a distance $r$ due to a single point charge $q$ has the magnitude

$$E = \left(\frac{1}{4\pi\varepsilon_0 K}\right)\left(\frac{q}{r^2}\right) \Rightarrow E \propto \frac{1}{r^2}$$

and direction along the line joining the point charge $q$ and point $P$, being away for the positive charge and towards for the negative charge.

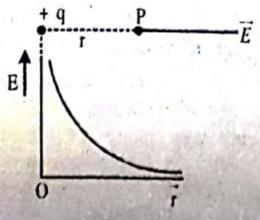



Fig. 3.10

**Electric field due to Many Point Charges**

The electric field due to many point charges $q_j \equiv q_1, q_2, q_3, \ldots\ldots\ldots$ at a point $P$ at the distances $r_j \equiv r_1, r_2, r_3, r_4, \ldots\ldots\ldots$ from the charges $q_j$ is given by the superposition principle, i.e.,

$$\vec{E} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \vec{E}_4 + \ldots\ldots\ldots \equiv \sum_j \vec{E}_j$$

where $j = 1, 2, 3, 4, \ldots\ldots\ldots$ The magnitude $E_j$ due to a single point charge $q_j$ at the distance $r_j$ is

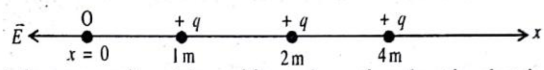
$$E_j = \left(\frac{1}{4\pi\varepsilon_0 K}\right)\left(\frac{q_j}{r_j^2}\right)$$

For example, the electric field at the origin ($x = 0$) due to an infinite number of positive point charges, each of the magnitude $q$, situated at the points $x = 1m, 2m, 4m, \ldots\ldots$ has the magnitude

$$E = \left(\frac{1}{4\pi\varepsilon_0 K}\right)\left(\frac{q}{1^2} + \frac{q}{2^2} + \frac{q}{4^2} + \frac{q}{8^2} + \ldots\ldots\right)$$

$$= \left(\frac{q}{4\pi\varepsilon_0 K}\right)\left(1 + \frac{1}{4} + \frac{1}{16} + \frac{1}{64} + \ldots\ldots\ldots\right) = \left(\frac{q}{4\pi\varepsilon_0 K}\right)\left(\frac{1}{1-1/4}\right) = \frac{4}{3}\left(\frac{q}{4\pi\varepsilon_0 K}\right)$$

and the minus $x$-direction.



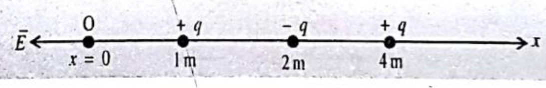

If the infinite number of point charges are alternately positive and negative, then the electric field has the magnitude

$$E = \left(\frac{1}{4\pi\varepsilon_0 K}\right)\left(\frac{q}{1^2} - \frac{q}{2^2} + \frac{q}{4^2} - \frac{q}{8^2} + \ldots\ldots\right)$$

$$= \left(\frac{q}{4\pi\varepsilon_0 K}\right)\left(1 - \frac{1}{4} + \frac{1}{16} - \frac{1}{64} + \ldots\ldots\right)$$

$$= \left(\frac{q}{4\pi\varepsilon_0 K}\right)\left(\frac{1}{1+1/4}\right) = \frac{4}{5}\left(\frac{q}{4\pi\varepsilon_0 K}\right)$$

and the minus $x$-direction.




**Charged Conductor Carrying no Currents**

Any charge given to a conductor spreads over the whole external-most surfaces $S$ of the conductor, with the varying surface charge density $\sigma$. The surface charge density $\sigma$ is more on the bulging parts and less on the flat parts of the external-most surface. No part of the charge given resides over the inner surfaces, $S_1$, $S_2$ ........ etc. of the conductor, *i.e.*, the cavity surfaces, if any.

The electric field $\vec{E}$ is vanishing inside of the external-most surface $S$ and, even, inside of the inner surfaces $S_1$, $S_2$,.... of the conductor. The field is nonvanishing on and near the surface $S$ in the direction normal to it, being away from the conductor for the positive charge and towards for the negative charge.

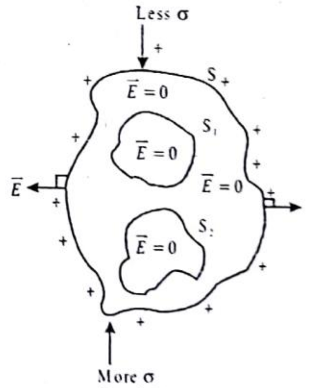


*Fig. 3.11*

$$E = \frac{\sigma}{\varepsilon_0 K}$$

which shows that the field is independent of the position and depends on the surface charge density $\sigma$.

## ELECTRIC LINES OF FORCE OR ELECTRIC FIELD LINES

**(i)** The concept of electric field was introduced by Michael Faraday.
The magnitude of electric field strength at any point is measured by the number of electric lines of force passing per unit small area around that point normally and the direction of field at any point is given by the tangent to the line of force at the point.

**(ii)** An electric line of force is that imaginary smooth curve drawn in an electric field along which a free isolated unit positive (initially at rest) charge moves.

**Properties :**

**(1)** The lines of force diverge out radially from a +ve charge and converge at a – ve charge. More correctly the lines of force are always directed from higher to lower potential.

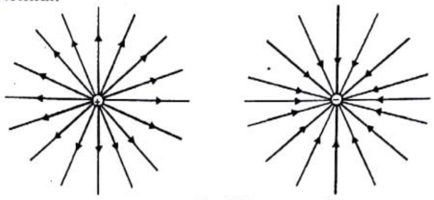


*Fig. 3.12*

**(2)** The tangent drawn at any point on line of force gives the direction of force acting on a positive charge placed at that point.

**(3)** Two lines of force never intersect. If they are assumed to intersect, there will be two directions of electric field at the point of intersection, which is impossible.

**(4)** These lines have a tendency to contract in tension like a stretched elastic string. This actually explains attraction between opposite charges.

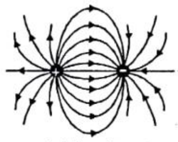



*Fig. 3.13*

**(5)** These lines have a tendency to separate from each other in the direction perpendicular to their length. This explains repulsion between like charges.

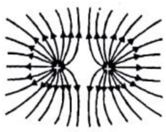



*Fig. 3.14*

**(6)** The no. of lines originating or terminating on a charge is proportional to the magnitude of charge. In rationalised MKS system $(1/\varepsilon_0)$ electric lines are associated with unit charge. So if a body encloses a charge $q$. Total line of force associated with it (called flux) will be $\dfrac{q}{\varepsilon_0}$.

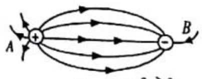



*Fig. 3.15* $q_A > q_B$

**(7)** Total lines of force may be fractional as lines of force are imaginary.

**(8)** Lines of force ends or strarts normally on the surface of a conductor.

**(9)** If there is no electric field there will be no lines of force.

**(10)** Lines of force per unit area normal to the area at a point represents magnitude of intensity, crouded lines represent strong field while distant lines represent weak field.

**(11)** Electric lines of force differ from magnetic lines of force.

**(a)** Electric lines of force never form closed loop while magnetic lines are always closed or extended to infinity.

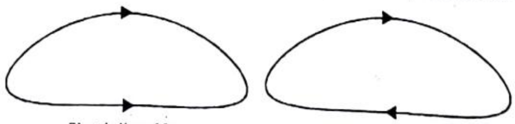
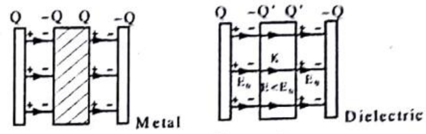



*Fig. 3.16*

(b) Electric lines of force always emerge or terminate normally on the surface of charged conductor, while magnetic lines emerge or terminate on the surface of a magnetic material at any angle.

(c) Electric lines of force do not exist inside a conductor but magnetic lines of force may exist inside magnetic material. Lines of force do not exist inside a conductor (as field inside a conductor is zero) as shown. (Electrostatic shielding)




(a) Fig. 3.17 (b)

## CHECK Point

☛ **Which among the curves shown in Figure cannot possibly represent electrostatic field lines?**

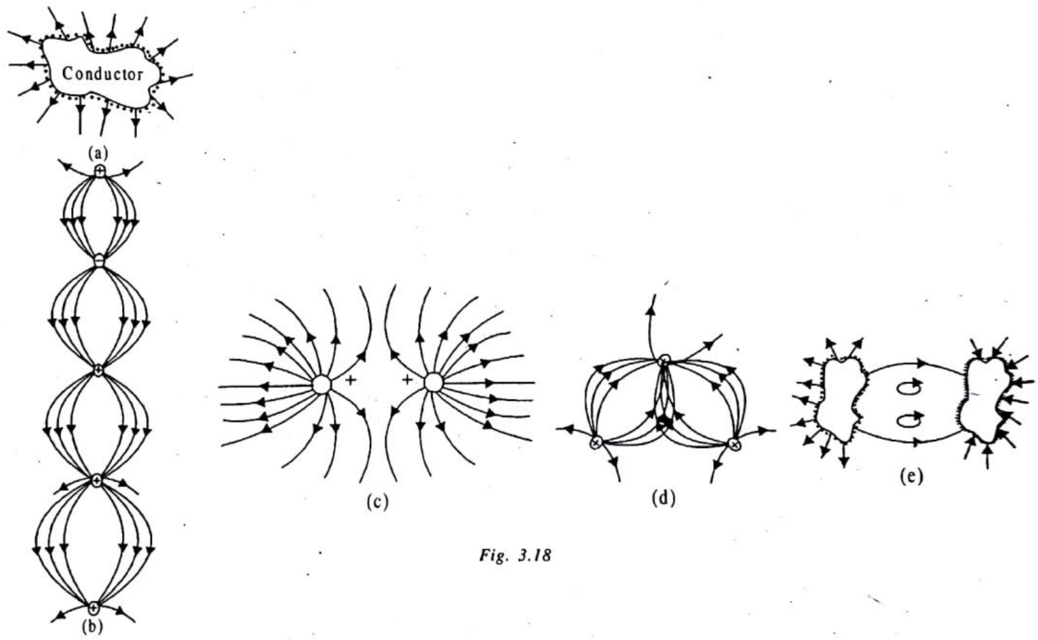



*Fig. 3.18*

### SOLUTION

(a) It is wrong, because electric field lines must be normal to the surface of conductor outside it.

(b) It is wrong because field lines cannot start or originate from negative charge, and also cannot end or submerge into positive charge.

(c) It is correct

(d) It is wrong because electric field lines never intersect each other.

(e) It is wrong because electric field lines cannot form closed loops.

## ELECTRIC FLUX

A surface $S$ may be considered to be placed in an electric field $\vec{E}$ and imagined to be subdivided into many elementary parts, each of area $\Delta S$. The electric field over each elementary area may be assumed uniform. Then, the electric flux through an elementary part is defined as

$$\Delta\phi_E = (E\cos\theta)\,\Delta S = \vec{E}.\Delta\vec{S}$$

where $E \cos \theta$ is the normal component of $\vec{E}$ and $\Delta\vec{S}$ is a surface vector, having its magnitude equal to the area of elementary part and its direction outwards along the normal. Evidently, this electric flux may be positive, or zero, or negative, depending on the angle $\theta$ between the electric field $\vec{E}$ and normal. Then, the electric flux through the whole surface $S$ is

$$\phi_E = \Delta\phi_{E_1} + \Delta\phi_{E_3} + \dots\dots\dots$$

where the summation is performed over all the elementary parts of $S$. By definition, $\phi_E$ is a scalar which is positive for the outward flux and negative for the inward flux.

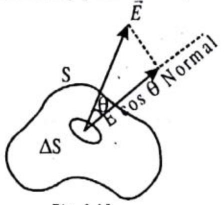



Fig. 3.19

For a closed surface $S$ placed in an electric field $\vec{E}$ in vacuum, we have

$$\phi_E = \frac{q}{\varepsilon_0}$$

where $q$ is the total charge anywhere inside of the surface. If there is no charge inside of the surface, then $\phi_E = 0$. This statement is called the 'Gauss's Law, or Flux Theorem'.

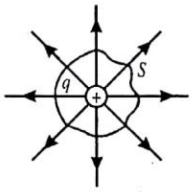



Fig. 3.20

If a charge $+q$ is situated at the centre of a cubical surface $S$, the total electric flux emanated from the charge and passing through all the six identical faces is $\phi_E = q/\varepsilon_0$ so that the electric flux through each of the faces becomes

$$\phi_E = \frac{q}{6\varepsilon_0}$$

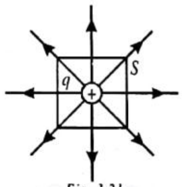



Fig. 3.21

If the charge $+q$ is fastened at the centre of ceiling of a cubical surfaces $S$, the electric flux emanated from the charge and falling on the walls and floor is

$$\phi_E = \frac{q}{2\varepsilon_0}$$

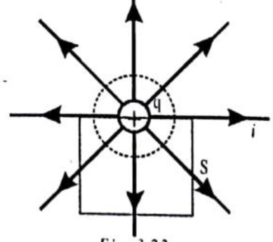



Fig. 3.22

If the charge $+q$ is placed at one corner of the cubical surface $S$, this corner may be imagined to be common to the eight identical cubical surfaces so that the electric flux through one cubical surface becomes

$$\phi_E = \frac{q}{8\varepsilon_0}$$

and then, the electric flux through each of the three faces meeting at that corner is zero and the electric flux through each of the other three faces is

$$\phi_E = \frac{q}{24\varepsilon_0}$$

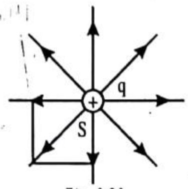



*Fig. 3.23*

**ILLUSTRATION 3.7**

A surface encloses an electric quadrupole. What is the total electric flux through the surface?

**SOLUTION:**

An electric quadrupole consists of the two electric dipoles, each one having the two point charges $+q$, $-q$ and the zero net charge. Therefore, the net charge of a quadrupole is zero, and then, according to the Gauss's Law, the total electric flux through the surface enclosing the quadrupole given by the net charge inside of the surface divided by the permittinity $\varepsilon_0$, is zero.

**ILLUSTRATION 3.8**

A cylinder of radius $R$ and length $L$ is placed in a uniform electric field $\vec{E}$, parallel to it's axis, as shown. Calculate the total electric flux through the surface of cylinder.

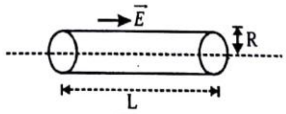



*Fig. 3.24*

**SOLUTION:**

The cylinder is simply placed in the uniform electric field $\vec{E}$ which may otherwise be in any direction, and it does not have any charge enclosed inside of it. Therefore, according to the Gauss's law, the total electric flux through the surface of cylinder must be zero.

## ELECTRIC POTENTIAL

Electric potential at a point in electric field is defined to be equal to the minimum work done by an external agent in moving a unit positive charge from infinity or a reference point to that point against the electrical force of the field.
Electric potential at a point in electric field is numerically equal but opposite in sign to the work performed by electrical force to bring unit positive charge from infinity to that point.
If W is the work done by external agent in bringing a positive test charge $q_0$ from infinity to a point then the potential V at that point,

$$V = \frac{W_{ext}}{q_0} \;;\; V = -\frac{W_E\text{(work done by electric field)}}{q_0}$$

Unit of potential is joule/coulomb or volt. (S.I. unit)

## Knowledge ENHANCER

**Potential due to Many Point Charges**

The electrostatic potential due to many point charges $q_j \equiv q_1, q_2, q_3, .......$ at a point at the distances $r_j \equiv r_1, r_2, r_3, ..........$, respectively, from the charges $q_j$ is given by the algebraic summation, i.e.,

$$V = V_1 + V_2 + V_3 + \equiv \sum_j V_j$$

where $j$ = 1, 2, 3, ....... The electrostatic potential due to a point charge $q_j$ at a point at the distance $r_j$ is

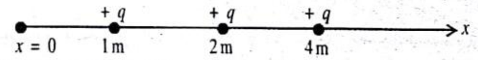
$$V_j = \left(\frac{1}{4\pi\varepsilon_0 K}\right)\left(\frac{q_j}{r_j}\right)$$

For example, the electrostatic potential at the origin $x = 0$ due to an infinite number of positive point charges, each of magnitude, $q$, situated at the points $x = 1m, 2m, 4m,$ ........ is

$$V = \left(\frac{1}{4\pi\varepsilon_0 K}\right)\left(\frac{q}{1} + \frac{q}{2} + \frac{q}{4} + ..............\right)$$

$$= \left(\frac{q}{4\pi\varepsilon_0 K}\right)\left(1 + \frac{1}{2} + \frac{1}{4} + ........\right)$$

$$= \left(\frac{q}{4\pi\varepsilon_0 K}\right)\left(\frac{1}{1-1/2}\right) = 2\left(\frac{q}{4\pi\varepsilon_0 K}\right)$$

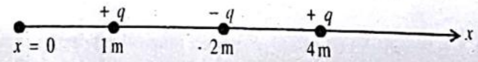



If the infinite number of point charges are alternately positive and negative, then

$$V = \left(\frac{q}{4\pi\varepsilon_0 K}\right)\left(\frac{q}{1} - \frac{q}{2} + \frac{q}{4} ..............\right)$$

$$= \left(\frac{q}{4\pi\varepsilon_0 K}\right)\left(1 - \frac{1}{2} + \frac{1}{4} .........\right)$$

$$= \left(\frac{q}{4\pi\varepsilon_0 K}\right)\left(\frac{1}{1+1/2}\right) = \frac{2}{3}\left(\frac{q}{4\pi\varepsilon_0 K}\right)$$




## ELECTRIC POTENTIAL DIFFERENCE

Potential deference between two points is equal to the minimum work done in moving a unit positive test charge from one point to the other.


$$V_B - V_A = \frac{W_{AB}}{q_0} \Rightarrow W_{AB} = q_0(V_B - V_A)$$

$W_E$ is the work done by the electric field then ;

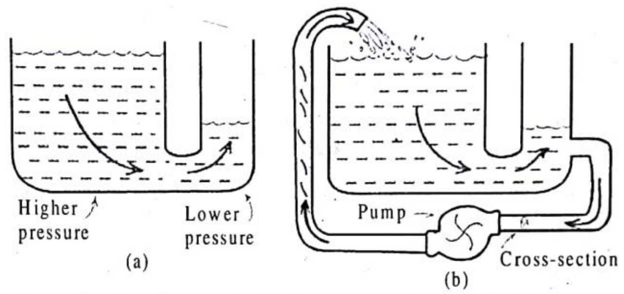
$$-(V_B - V_A) = \frac{W_E}{q_0} \Rightarrow W_E = -q_0(V_B - V_A)$$

$$W_{ext.} = -W_E$$

## UNDERSTANDING POTENTIAL DIFFERENCE

When the ends of a heat conductor are at different temperatures, heat energy flows from the higher temperature to the lower temperature. The flow ceases when both ends reach the same temperature. Similarly, when the ends of an electrical conductor are at different electric potentials – when there is a **potential difference** – charges in the conductor flow from the higher potential to the lower potential. The flow of charge persists until both ends reach the same potential. Without a potential difference, no flow of charge will occur.

To attain a sustained flow of charge in a conductor, some arrangement must be provided to maintain a difference in potential while charge flows from one end to the other. The situation is analogous to the flow of water from a higher reservoir to a lower one fig. Water will flow in a pipe that connects the reservoirs only as long as a difference in water level exists. The flow of water in the pipe, like the flow of charge in a wire, will cease when the pressures at each end are equal. (We imply this phenomenon when we say that water seeks its own level.) A continuous flow is possible if the difference in water levels – hence the difference in water pressures – is maintained with the use of a suitable pump (in Figure).




*(a) Water flows from the reservoir of higher pressure to the reservoir of lower pressure. The flow will cease when the difference in pressure ceases.*
*(b) Water continue to flow because a difference in pressure is maintained with the pump.*
*Fig. 3.25*

A sustained electric current requires a suitable pumping device to maintain a difference in electric potential – to maintain a voltage. Chemical batteries or generators are "electrical pumps" that can maintain a steady flow of charge. These devices do work to pull negative charges apart from positive ones. In chemical batteries, this work is done by the chemical disintegration of zinc or lead in acid, and the energy stored in the chemical bonds is converted to

electric potential energy.

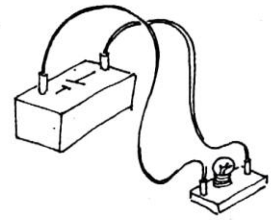


*Fig.3.26 Each coulomb of charge that is made to flow in a circuit that connects the ends of this 1.5V. Flashlight cell is energized with 1.5J.*

Generators separate charge by electromagnetic induction, a process we will describe in the next chapter. The work that is done (by whatever means) in separating the opposite charges is available at the terminals of the battery or generator. This energy per charge provides the difference in potential (voltage) that provides the "electrical pressure" to move electrons through a circuit joined to those terminals.

A common automobile battery will provide an electrical pressure of 12 volts to a circuit connected across its terminals. Then 12 joules of energy are supplied to each coulomb of charge that is made to flow in the circuit.

## EQUIPOTENTIAL SURFACES

A surface of constant, or uniform, potential $V$ is called the equipotential surface, e.g., the surface of a charged conductor carrying no electric currents, any spherical surface about a point charge as centre, any plane surface drawn parallel to and between the plates of a charged parallel-plate capacitor and so on. For a given charge distribution, the equipotential surfaces and eletric-field lines form an orthogonal system, i.e., they are mutually perpendicular. The equipotential surfaces do not intersect each other and they are closer in the region of stronger electric field and widely separated in the region of weaker electric field.

Fig. 3.27

A volume of constant, or uniform, potential $V$ is called the equipotential volume, *e.g.*, the volume of a charged conductor, carrying no electric currents.

### CHECK Point

- **Two charges 2 μC and –2 μC are placed at points A and B, 6 cm apart.**
  **(a) Identify an equipotential surface of the system.**
  **(b) What is the direction of the electric field at every point on this surface?**

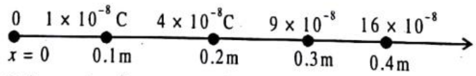
**SOLUTION**

(a) Since it is an electric dipole, so a plane normal to AB and passing through its mid-point has zero potential everywhere.
(b) Normal to the plane in the direction AB.

### ILLUSTRATION 3.9

Ten positively charged particles have the charges $1\times10^{-8}\,C, 4\times10^{-8}\,C, 9\times10^{-8}\,C, 16\times10^{-8}\,C$ ........, $100\times10^{-8}\,C$ and are situated on the $x$-axis at the points $x = 0.1$ m, 0.2 m, 0.3 m, ........, 1.0 m, respectively. Calculate the electric potential at the origin $O$.

**SOLUTION:**




The electric potential at the origin $O$ due to the given ten positively-charged particles is

$$V = (9\times10^9)\times\left[\frac{1\times10^{-8}}{0.1}+\frac{4\times10^{-8}}{0.2}+\frac{9\times10^{-8}}{0.3}+........+\frac{100\times10^{-8}}{10}\right]$$

$$= 90\times[10+20+30+..........+100]$$
$$= 900\times[1+2+3+............+10]$$
$$= 900\times55$$
$$= 4.95\times10^4 \text{ volt.}$$

### ILLUSTRATION 3.10

A uniform electric field of 10 N/C exists in the vertically downward direction. Find the increase in the electric potential as we go up through a height of 0.5 m.

**SOLUTION:**

The increase in the electric potential $(V_B - V_A)$ as we go up from the point $A$ to the point $B$ through a height of 0.5 m is equal to the work done in displacing a charge of $+1C$ from $A$ to $B$ against the electric field. Therefore, we have

$$\Delta V = (V_B - V_A) = +10\frac{N}{C}\times1C\times0.5\text{m} = 5V$$

### ILLUSTRATION 3.11

A radioactive source, in the form of a metallic sphere of the radius 0.01 m, emits the β particles at the rate of $5\times10^{10}$ particles/s. The source is electrically insulated. How long will it take for it's electric potential to be raised by 2V, assuming that only 40% of the emitted β particles escape the source?

**SOLUTION :**

Say, the electric potential of the source is raised to the $2V$ in the time $t$ seconds. In this time, the total number of $\beta$ particles emitted from the radioactive source is

$$n = 5\times 10^{10}\times t$$

and the number of $\beta$ particles escaping the source is

$$n' = \frac{40}{100}\times 5\times 10^{10}\times t$$

The total charge of these $\beta$ particles is

$$q = -e\times n' = -e\times\frac{40}{100}\times 5\times 10^{10}\times t\ C$$

and hence, the total charge which appears on the radioactive source is

$$q' = -q = +e\frac{40}{100}\times 5\times 10^{10}\times t\ C$$

Due to this charge, the source, being spherical and of radius $R = 0.01$ m, is raised to the electric potential of $2V$. Therefore,

$$2 = \left(\frac{1}{4\pi\varepsilon_0}\right)\left(\frac{q'}{R}\right)$$

$$2 = (9\times 10^9)\frac{\left(e\times\frac{40}{100}\times 5\times 10^{10}\times t\right)}{0.01}$$

$$\Rightarrow \qquad t = \frac{2\times 0.01\times 100}{9\times 10^9\times 1.6\times 10^{-19}\times 40\times 5\times 10^{10}} = \frac{1}{1440}\ \text{second.}$$

## ELECTROSTATIC POTENTIAL ENERGY

The electrostatic potential energy of a point charge $q$ placed at a point in the electric field $\vec{E}$ is given by

$$U = qV$$

i.e., it is the work done in displacing the point charge $q$ from the reference point which is arbitrarily chosen at infinity and U is arbitraily taken zero there, to that point. The electrostatic potential energy gain $(U_B - U_A)$ in displacing the charge $q$ from the point $A$ to the point $B$ in the electric field $\vec{E}$ is equal to the work done in displacing the charge $q$ from $A$ and $B$. Therefore,

$$(U_B - U_A) = q(V_B - V_A)$$

where $(V_B - V_A)$ is the electrostatic potential difference between the points $A$ and $B$. This gain may be positive, or zero, or negative, depending on the charge and the electrostatic potential difference. For example, when an electron of charge $-e$ moves from a lower to higher potential, it loses its electrostatic potential energy. The loss, or gain, of electrostatic potential energy is normally expressed in the unit, i.e.,

$$1\ eV \equiv 1.6\times 10^{-19}\ \text{J}$$

The electrostatic potential energy of a system of two point charge $q_1$ and $q_2$, separated by a distance $r_{12}$, is

$$U = \left(\frac{1}{4\pi\varepsilon_0 K}\right)\left(\frac{q_1 q_2}{r_{12}}\right)$$

which is defined as the amount of work done in assembling the two point charges from the infinite separation between them. The electrostatic potential energy of a system of three point charges $q_1$, $q_2$ and $q_3$, having the separation $r_{12}$ between $q_1$, $q_2$, separation $r_{23}$ between $q_2$, $q_3$ and separation $r_{31}$ between $q_3$, $q_1$, becomes

$$U = \left(\frac{1}{4\pi\varepsilon_0 K}\right)\left(\frac{q_1 q_2}{r_{12}} + \frac{q_2 q_3}{r_{23}} + \frac{q_3 q_1}{r_{31}}\right)$$

which is equal to the amount of work done in assembling the system of three point charges from the infinite separations between them.

## CHECK Point

**A balloon may easily be charged to several thousand volts. Does that mean it has several thousand Joules of energy? Explain.**

**SOLUTION**

No, it doesn't mean that the balloon has several thousand joules of energy always. It can have several thousand joules of energy only if the balloon acquires high charge.

## ILLUSTRATION 3.12

Three point charges $q_1$, $q_2$ and $q_3$ of $0.1C$ each are placed at the corners of an equilateral triangle of the side $1\text{m}$. If this system is supplied energy at the rate of 1kW, then how much time will be required to move one of the charges to the mid point of the line joining the others?

**SOLUTION:**

The three charges are at the corners of an equilateral triangle, as shown.

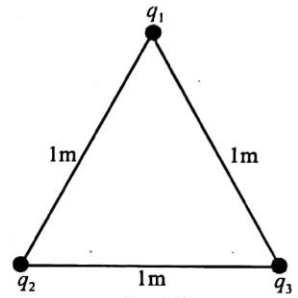


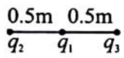
*Fig. 3.28*

The total electrostatic potential energy of the system is

$$U_1 = \left(\frac{1}{4\pi\varepsilon_o}\right)\left(\frac{q_1q_2}{r_{12}}+\frac{q_2q_3}{r_{23}}+\frac{q_3q_1}{r_{31}}\right)$$

$$= (9oe10^9)\left(\frac{0.1\times0.1}{1}+\frac{0.1\times0.1}{1}+\frac{0.1\times0.1}{1}\right) = 2.7\times10^8\text{J}$$

When one of the charges, say, $q_1$, is moved to the mid point of the line joining the other two charges, as shown,




the total electrostatic potential energy of the system will be

$$U_2 = (9\times10^9)\left(\frac{0.1\times0.1}{0.5}+\frac{0.1\times0.1}{0.5}+\frac{0.1\times0.1}{1}\right)$$

$$= 4.5\times10^8\text{J}$$

Then, the total energy supplied to the system becomes

$$\Delta U = U_2 - U_1 = (4.5-2.7)\times10^8 = 1.8\times10^8 J$$

As the power supplied to the system is $1kW \equiv 1000W$, we have the time taken in supplying the energy $\Delta$U, i.e.,

$$t = \frac{1.8\times10^8}{1000} = 1.8\times10^5 s \equiv 50h$$

## ILLUSTRATION 3.13

Two identical point charges, $+q$ and $+q$ are placed on the $x$-axis at the points $x = a$ and $x = -a$, respectively. A third point charge $Q$ is placed at the origin $x = 0$. Prove that the change in the lectrostatic potential energy of $Q$ is approximately,

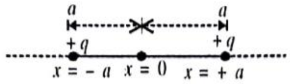
$$\Delta U = \left(\frac{1}{4\pi\varepsilon_0}\right)\left(\frac{2Qqd^2}{a^3}\right)$$

when it is displaced by a distance $d << a$ along the $x$-axis.

**SOLUTION :**

Before the displacement of the point charge $Q$, it's electrostatic potential energy is

$$U_1 = \left(\frac{1}{4\pi\varepsilon_0}\right)\left(\frac{Qq}{a}+\frac{Qq}{a}\right) = \left(\frac{1}{4\pi\varepsilon_0}\right)\left(\frac{2Qq}{a}\right)$$




When $Q$ is displaced by a distance $d << a$ in the $+x$ direction, then it's electrostatic potential energy becomes

$$U_2 = \left(\frac{1}{4\pi\varepsilon_0}\right)\left[\frac{Qq}{(a+d)}+\frac{Q}{(a-d)}\right] = \left(\frac{1}{4\pi\varepsilon_0}\right)\left[\frac{2aQq}{(a^2-d^2)}\right]$$

$$= \left(\frac{1}{4\pi\varepsilon_0}\right)\left(\frac{2Qq}{a}\right)\left(1-\frac{d^2}{a^2}\right)^{-1} \approx \left(\frac{1}{4\pi\varepsilon_0}\right)\left(\frac{2Qq}{a}\right)\left(1+\frac{d^2}{a^2}\right)$$

Now, the change, i.e., increase, in the electrostatic potential energy of $Q$ becomes

$$\Delta U = U_2 - U_1$$

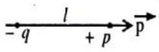
$$\approx \left(\frac{1}{4\pi\varepsilon_0}\right)\left(\frac{2Qq}{a}\right)\left(\frac{d^2}{a^2}\right) \approx \left(\frac{1}{4\pi\varepsilon_0}\right)\left(\frac{2Qqd^2}{a^3}\right)$$

## ELECTRIC DIPOLE

An electric dipole is a system of two unlike point charges $-q, +q$, having a negligibly small separation $l$. It has no net charge and it is characterised only by its electric dipole moment, i.e.

$$\vec{p} = q\vec{l}$$

where $q$ is the magnitude of the point charges, $\vec{l}$ is the vector separation directed from the negative point charge to the positive point charge. Evidently, $\vec{p}$ has the magnitude $(ql)$ and the direction from the negative point charge to the positive point charge.




## Knowledge ENHANCER

**The torque** $\tau$ on a dipole in uniform electric field as shown in figure is given by, $\tau = qE \times 2\ell\sin\theta = \vec{p}\times\vec{E}$

So $\tau$ is maximum, when dipole is $\perp$ to field & minimum (=0) when dipole is parallel or antiparallel to field.

If $\vec{p} = p_x\hat{i}+p_y\hat{j}+p_z\hat{k}$ and $\vec{E} = E_x\hat{i}+E_y\hat{j}+E_z\hat{k}$

Then $\vec{\tau} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ p_x & p_y & p_z \\ E_x & E_y & E_z \end{vmatrix}$

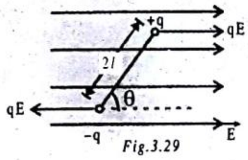



Fig.3.29

**The work done in rotating the dipole** from equilibrium through an angle $d\theta$ is given by

$$dW = \tau d\theta = pE\sin\theta d\theta$$

and from $\theta_1 \to \theta_2$,

$$W = \int_{\theta_1}^{\theta_2} dW = \int_{\theta_1}^{\theta_2} pE\sin\theta d\theta$$

## Knowledge ENHANCER

If $\theta_1 = 0$ i.e equilibrium position, then

$$W = \int_0^{\theta_2} pE\sin\theta d\theta = pE(1-\cos\theta_2)$$

**Workdone in rotating an electric dipole** in uniform electric field from $\theta_1$ to $\theta_2$ is $W = pE(\cos\theta_1 - \cos\theta_2)$

**Time period of a dipole** in uniform electric field is

$$T = 2\pi\sqrt{\frac{I}{pE}}$$

where I = Moment of Inertia of the dipole about the axis of rotation.

**Potential energy of an electric dipole** in an electric field is,

$$U = -\vec{p}.\vec{E} \quad \text{i.e: } U = -pE\cos\theta$$

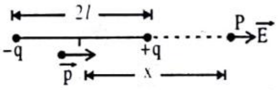
where $\theta$ is the angle between $\vec{E}$ and $\vec{p}$.

We can also write

$$U = p_xE_x + p_yE_y + p_zE_z$$

***Electric field due to an electric dipole***

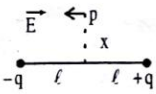
(a) Axial line (end-on position)




$\vec{p}$ and $\vec{E}$ are parallel

$$E_{Ax} = \frac{1}{4\pi\epsilon_0}.\frac{2px}{(x^2-l^2)^2} \quad \text{when } x >> l$$

(b) Equatorial line (Broad - side on potential)




$$E_{eq} = \frac{1}{4\pi\epsilon_0}.\frac{p}{(x^2+\ell^2)^{3/2}} \quad \text{where } x >> l$$

$\vec{p}$ and $\vec{E}$ are anti parallel i.e when $x >> l$,

$$E_{Ax} = 2E_{eq}$$

(c) At any point (for first dipole)

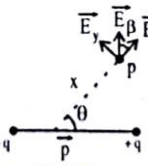



Fig.2.30

$$E = \frac{1}{4\pi\epsilon_0}\frac{p}{x^3}\sqrt{3\cos^2\theta+1}\;;\; \tan\beta = \frac{1}{2}\tan\theta$$

(d) Electric field intensity due to a point charge varies inversely as cube of the distance and in case of quadrupole it varies inversely as the fourth power of distance from the quadrupole.

Foundation Physics for class X Book 1 for IIT JEE standard 10 by Prof. K K Anand SmartEdu

**ILLUSTRATION 3.14**

Calculate the electric intensity due to a dipole of length 10 cm and having a charge of 500 $\mu$ $C$ at a point on the axis distant 20 cm from one of the charges in air.

**SOLUTION:**

The electric intensity on the axial line of the dipole is given by

$$E_{axial} = \frac{1}{4\pi\varepsilon_o} \times \frac{2rp}{\left[r^2 - \left(\frac{a}{2}\right)^2\right]^2}$$

Here a = 10 cm or $a/2 = 5 \times 10^{-2}$ m, $r = (20+5)$ cm $= 25 \times 10^{-2}$ m, $p = q \times a = (500 \times 10^{-6}) \times (10 \times 10^{-2}) = 5 \times 10^{-5}$ C-m

$$E_{axial} = (9\times10^9)\times\frac{2\times(25\times10^{-2})\times(5\times10^{-5})}{10^{-8}[(25)^2-(5)^2]^2} = 3.25\times10^7 \text{ N-C}$$

## CAPACITORS AND CAPACITANCE

A capacitor or condenser consists of two conductors separated by an insulator or dielectric. The conductors carry equal and opposite charges $\pm Q$. It is an electrical device that store electric charge. The conductors used in capacitor are called plates. Whatever their shape may be (square, circular, rectangular, spherical or cylindrical, all are called plates). A single conductor acts as a conductor, with the assumption that the other plate is at infinity and earthed. If some how the potential is lowered, to bring it once again to the same potential more charge can be given to it, so the capacitance of the conductor can be increased. The capacitance of a conductor is gently increased when an earth connected conductor is placed near it.

**Capacitance**

When charge is given to an isolated body its potential increases

i.e., $q \propto V \Rightarrow q = CV \Rightarrow C = \frac{q}{V}$

if, $V = 1 \Rightarrow C = q$

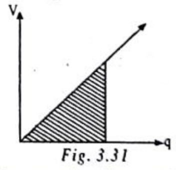



Fig. 3.31

**(1)** The ability to store charge is called capacitance of the capacitor. Capacitance of a body is numerically equal to the charge required to raise the potential by unit.

**(2)** Units : SI unit of $C \Rightarrow C$/volt = Farad ($F$)

C.G.S. unit $\rightarrow 1F = \frac{C}{\text{volt}} = \frac{3\times10^9 \text{ stat C}}{1/300 \text{ stat volt}}$

$\Rightarrow 1F = 900 \times 10^9 = 9 \times 10^{11}$ stat Farad.

Dimensions : $[M^{-1} L^{-2} T^4 A^2]$

In case of spherical conductor

$V = \frac{q}{4\pi\varepsilon_0 R} \Rightarrow \frac{q}{V} = C = 4\pi\varepsilon_0 R$

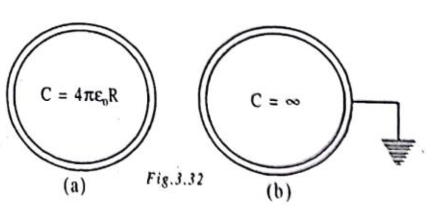



Fig.3.32

If we assume the earth to be a conducting sphere of radius 6400 km its capacity will be $C = 4\pi\varepsilon_0 R = 711\ \mu F$.

**(3)** The capacity of the body is independent of the charge given to the body or its potential raised and depends on its shape and size only. $C \propto q^0, C \propto V^0$

*Capacitance depends on :*

**(a)** Area of the conductor : If the surface area of a conductor is increased keeping charge q const. Its potential decreases and hence the capacity increases $C = \frac{q}{V}$

**(b)** The presence of other conductor in the vicinity of the charged conductor.
The presence of other conductor near a charged conductor decreases the potential of the charged conductor, there by the capacity increases.

**(c)** The medium around the charged conductor : If the capacity of the conductor is $C$ when air is the medium around it, then the capacity becomes $KC$ when another medium of dielectric constant $K$ is around it. This is because of the reason that potential becomes $V/K$.

## ENERGY STORED IN A CAPACITOR

When a conductor is charged its potential changes from 0 to $V$ and work is done against repulsion between charge stored on the conductor and charge coming from the charging body. This work is stored as electrostatic potential energy ($U$).

$$U = \frac{q^2}{2C} = \frac{1}{2}qV = \frac{1}{2}CV^2.$$

The energy is stored in the electric field between the plates of the capacitor.

- *The energy stored per unit volume in the electric field between the plates is called energy density.*
- $u = \frac{1}{2}\varepsilon_0 E^2 = \frac{1}{2}\frac{\sigma^2}{\varepsilon_0}$.

## WORK DONE BY BATTERY

Work done by battery is given by

**W = Charge that flow through battery × battery EMF**

Whenever there is a charging of capacitor, work done by battery, in part is stored as electrostatic energy in between capacitor plates and remaining is dissipated as heat due to charge flow through connecting wires.

In general, heat produced is given by

H = Work done by battery – Energy stored in capacitor

## TYPES OF CAPACITORS

Capacitors are mainly of three types :

(1) Parallel plate capacitor

(2) Spherical capacitor

(3) Cylindrical capacitor

**(1) Parallel plate capacitor (PPC) :** A PPC consists of two equal parallel metal plates facing each other and separated by a dielectric ($\varepsilon_r$). The plates may be square, rectangular or circular in shape.

Let us consider a parallel-plate capacitor, having a charge $q$ and the surface charge density $\sigma$ on its two plates with a separation $d$ and area $A$ of each face. The electric field between the two plates is

$$E_0 = \frac{\sigma}{\varepsilon_0} = \frac{q}{\varepsilon_0 A}$$

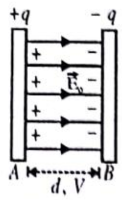


Fig. 3.33

and electric potential difference across them is

$$V = (V_A - V_B) = E_0 d = \frac{qd}{\varepsilon_0 A}$$

Then, the capacitance of capacitor becomes

$$C = \frac{q}{V} = \frac{\varepsilon_0 A}{d}$$

**In case of PCC**

(i) Capacity is directly proportional to effective over-laping area of the plate $C \propto A$.

(ii) Capacity is inversely proportional to the distance between the plate i.e. $C \propto 1/d$.

(iii) Capacity is independent of charge given, potential raised or nature of metal and thickness of plates.

**(2) Spherical capacitor**

**(i) Outer Spherical Conductor Grounded**

Let us consider a spherical capacitor, having the two spherical conductors $A$ and $B$ of the radii $a$ and $b$, respectively, with the conductor $B$, grounded. When a charge $+q$ is given to the inner spherical conductor $A$, a charge $-q$ is induced on the inner surface and a charge $+q$ is induced on the outer surface of the outer conductor $B$. The induced charge $+q$ flows to the ground and only, the induced charge $-q$ remains on the inner surface of the outer conductor $B$.

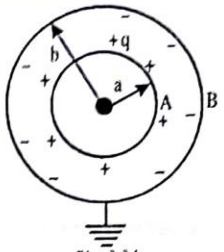


Fig. 3.34

The electric potential of the inner spherical conductor $A$ due to the two charges, $+q$ on $A$ and $-q$ on $B$, becomes

$$V_A = \left(\frac{1}{4\pi\varepsilon_0 K}\right)\left(\frac{+q}{a}+\frac{-q}{b}\right) = \left(\frac{q}{4\pi\varepsilon_0 K}\right)\left(\frac{b-a}{ab}\right)$$

The electric potential of the outer spherical conductor $B$ due to the two charges becomes

$$V_B = \left(\frac{1}{4\pi\varepsilon_0 K}\right)\left(\frac{+q}{a}+\frac{-q}{b}\right) = 0$$

Then, the capacitance of the spherical capacitor, having the two spherical conductors $A$ and $B$, with the outer conductor $B$ grounded, is given by

$$C = \frac{q}{(V_A - V_B)} = \frac{q}{V_A} = (4\pi\varepsilon_0 K)\left(\frac{ab}{b-a}\right)$$

When the outer conductor $B$ assumes the infinitely large size, *i.e.*, the radius $b$ tends to infinity, only the inner spherical conductor remains on the scene and its capacitance is given by

$$C = (4\pi\varepsilon_0 K) = \left(\frac{a}{1-\frac{a}{b}}\right) = (4\pi\varepsilon_0 K)a$$

The capacitance of our earth which is assumed to be spherical conductor of mean radius of 6400 km, is about

$$C = (4\pi\varepsilon_0)\, a = \frac{6400\times 1000}{9\times 10^9} F \approx 711 \mu F$$

**(ii) Inner Spherical Conductor Grounded**

Let us, now, consider a spherical capacitor, having the two spherical conductors $A$ and $B$ of the radii $a$ and $b$, respectively, with the inner spherical conductor $A$ grounded. In order to calculate the capacitance of such a spherical capacitor, we may introduce a third grounded and concentric spherical conductor $D$ of the radius $d > b > a$. Then, the system of three conductors is equivalent to a parallel combination of the two spherical capacitors of capacitances $C_1$, $C_2$, as shown in the figure.

The capacitance of the system of three conductors becomes

$$C = C_1 + C_2$$

$$= (4\pi\varepsilon_0 K)\left(\frac{ab}{b-a}\right) + (4\pi\varepsilon_0 K)\left(\frac{bd}{d-b}\right)$$

$$= (4\pi\varepsilon_0 K)\left(\frac{ab}{b-a}+\frac{bd}{d-b}\right)$$

$$= (4\pi\varepsilon_0 K)\left(\frac{ab}{b-a}+\frac{bd}{1-b/d}\right)$$

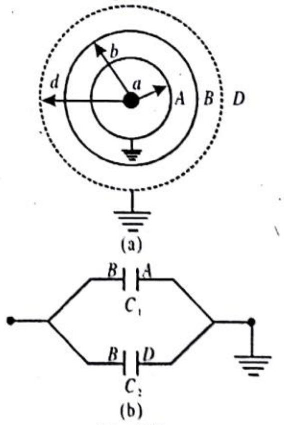


Fig. 3.35

When the conductor $D$ assumes the infinity large size, i.e., the radius $d$ tends to infinity, only the spherical conductors $A$, $B$ remain on the scene and the capacitance of system, then, becomes

$$C = (4\pi\varepsilon_0 K)\left(\frac{ab}{b-a}+b\right) = (4\pi\varepsilon_0 K)\left(\frac{b^2}{b-a}\right)$$

which is more than the capacitance of the system, with the outer spherical conductor $B$ grounded, by an amount $(4\pi\varepsilon_0 K)b$, i.e., the capacitance of the outer spherical conductor $B$ only.

**ILLUSTRATION 3.15**

The radius of circular plates of a parallel-plate capacitor is $r$. What is the distance between the plates, if it's capacitance, with the air as dielectric, is equal to that of an isolated sphere of radius $r'$ in air?

**SOLUTION:**

The capacitance of parallel-plate capacitor, with the air as dielectric, is

$$C = K\left(\frac{\varepsilon_0 A}{d}\right) = K\left(\frac{\varepsilon_0 \pi r^2}{d}\right)$$

where $A = \pi r^2$ is the area of one face of each plate of capacitor, $d$ is the separation between the plates of capacitor and $K$ is the dielectric constant of air. Equating this capacitance to the capactance of an isolated sphere of radius $r'$ in air, i.e.,

$$C' = (4\pi\varepsilon_0 K)r'$$

we have, $$K\left(\frac{\varepsilon_0 \pi r^2}{d}\right) = (4\pi\varepsilon_0 K)r'$$

$$\Rightarrow \quad d = \left(\frac{r^2}{4r'}\right)$$

**(3) Cylindrical capacitor**

A cylindrical capacitor consists of the two coaxial cylindrical conductors $A$ and $B$ of the radii $a$ and $b$, respectively, with the outer cylindrical conductor $B$ grounded. If the inner cylindrical conductor $A$ is given a charge per unit length of $+\lambda$, a charge per unit length of $-\lambda$ is induced on the inner surface of the outer cylindrical conductor $B$.

The electric field between the cylindrical conductors at the distance $r$ from the common axis is

$$E = \frac{\lambda}{2\pi\varepsilon_0 K r} \text{ for } (a < r < b)$$

which gives the potential for the two cylindrical conductors

$$V_A = -\left(\frac{\lambda}{2\pi\varepsilon_0 K}\right)\log_e a + \text{constant}$$

$$V_B = -\left(\frac{\lambda}{2\pi\varepsilon_0 K}\right)\log_e b + \text{constant}$$

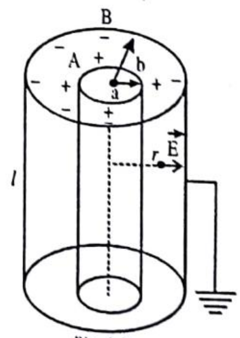


Fig. 3.36

The electric potential difference between the two cylindrical conductors becomes

$$V = (V_A - V_B) = \left(\frac{\lambda}{2\pi\varepsilon_0 K}\right)\log_e\left(\frac{b}{a}\right)$$

and then, the capacitance of the cylindrical capacitor becomes

$$C = \frac{q}{V} = \frac{\lambda l}{V} = \frac{(2\pi\varepsilon_0 K)l}{\log_e(b/a)} = \frac{(2\pi\varepsilon_0 K)l}{2.3030\times\log_{10}(b/a)}$$

where the charge on the capacitor is $q = \lambda l$, $l$ being the length of capacitor.

To increase the capacity of a cylindrical capacitor

(i) K or $\varepsilon_r$ symbol be more

(ii) b/a should be less i.e. $b \approx a$

(iii) Length of the cylinder (L) should be more.

**ILLUSTRATION – 3.16**

Two cylindrical capacitors, each of the capacitance of $2.2\mu F$, are kept with their outer cylinders in contact and their inner cylinders connected through a conducting wire, as shown. What is the equivalent capacitance of system as a whole?

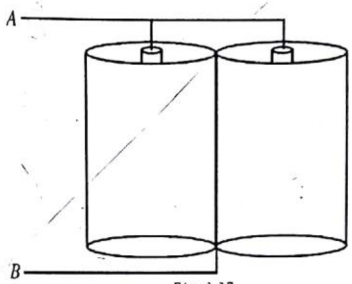



Fig. 3.37

**SOLUTION:**

The given system is a parallel combination of two cylindrical capacitors, each of capacitance of 2.2 $\mu F$, as shown.

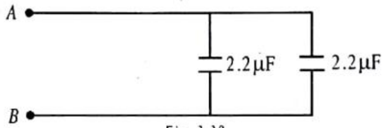



Fig. 3.38

Therefore, the equivalent capacitance of system as a whole is

$$C = 2.2 + 2.2 = 4.4\,\mu\text{F}$$

**CHECK Point**

☛ **What meaning would you give to the capacitance of a single conductor?**

**SOLUTION**

It means thata single conductor is a capacitor whose other plate can be considered to be at infinity.

## COMBINATION OF CAPACITORS

**Series Combination**

Let us consider a number of capacitors, connected in series, as shown.

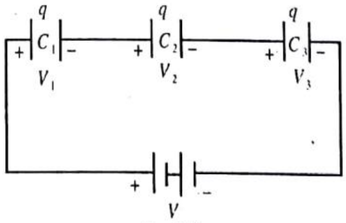



Fig. 3.39

They have the same charge $q$ but the different electric potential differences $V_1$, $V_2$, $V_3$............ across them due to their different capacitances $C_1$, $C_2$, $C_3$, ......... . The total electric potential difference applied across the combination is

$$V = V_1 + V_2 + V_3 + \ldots\ldots\ldots\ldots$$

$$= \frac{q}{C_1} + \frac{q}{C_2} + \frac{q}{C_3} + \ldots\ldots\ldots$$

$$= q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots\ldots\ldots\right)$$

Therefore, the equivalent capacitance $C$ of the series combination is given by

$$\frac{1}{C}=\frac{V}{q}=\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}+\ldots\ldots\ldots$$

Evidently, therefore, the equivalent capacitance $C$ is smaller than each one of the capacitances of combination.

**Parallel Combination**

We, now, consider a number of capacitors, connected in parallel, as shown. They have the same electric potential difference $V$ across them, but the different charges $q_1, q_2, q_3$ ......... on them due to their different capacitances $C_1, C_2, C_3$ ....... .

The total charge of the combination is

$$q=q_1+q_2+q_3+\ldots\ldots\ldots$$
$$=C_1V+C_2V+C_3V+\ldots\ldots\ldots$$
$$=V(C_1+C_2+C_3+\ldots\ldots\ldots)$$

from which we have the equivalent capacitance of the combination, i.e.,

$$C=\frac{q}{V}=C_1+C_2+C_3\ldots\ldots$$

Evidently, therefore, the equivalent capacitance $C$ is more than each one of the capacitances of combination.

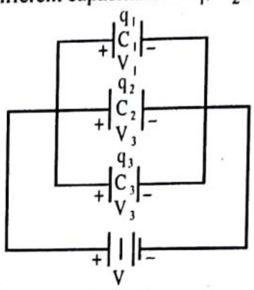


Fig. 3.40

**ILLUSTRATION – 3.17**

A circuit is shown in figure.

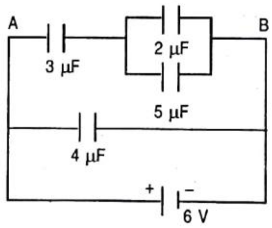


Fig. 3.41

Find the charge on the condenser having a capacity of 5 μF.

**SOLUTION:**

Potential difference between A and B = 6 volts. The condensers 2 μF and 5 μF are in parallel. Their effective capacitance, C = 2 + 5 = 7 μF.

The capacitance between A and B is given by $C'=\frac{C\times3}{C+3}=\frac{7\times3}{7+3}=\frac{21}{10}\mu F$

Total charge $Q=CV=\frac{21}{10}\times6=\frac{63}{5}\mu C$

Total potential difference across 3 μF is

$$V_1=\frac{Q}{3}=\frac{63}{5}\times\frac{1}{3}=\frac{21}{5}\text{ volts}$$

Hence the common potential difference across the condensers in parallel is

$$V_2=6-\frac{21}{5}=\frac{9}{5}V$$

So, the charge on 5 μF condenser is

$$Q=5\times V_2=5\times\frac{9}{5}=9\mu C$$

**ILLUSTRATION—3.18**

In the given circuit, consisting of the four capacitors and a battery, the potential difference across the 7 $\mu F$ capacitors is 6V. Then, calculate the potential differences across the remaining three capacitors and the battery emf.

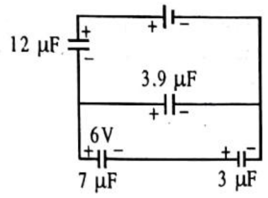



*Fig. 3.42*

**SOLUTION:**

The capacitors of $7\mu F$ and $3\mu F$ are in series and therefore, they have the same charge on them and the potential differences across them are in a ratio equal to the inverse ratio of capacitances. Therefore, the potential difference across the $3\mu F$ capacitor is

$$= \frac{6V \times 7\mu F}{3\mu F} = 14V$$

The potential difference across the parallel combination of $3.9\mu F$ capacitor with the series combination of $7\mu F$ and $3\mu F$ capacitor is, therefore, 20V. The total capacitance of this combination is

$$= 3.9 + \frac{7 \times 3}{7+3} = 6\mu F$$

which is in series with the capacitor of 12 $\mu F$ and therefore, they have same charge and the potential differences are in a ratio equal to the inverse ratio of capacitances. The potential difference across the $12\mu F$ capacitor becomes

$$= \frac{20V \times 6\mu F}{12\mu F} = 10V$$

and then, the battery emf becomes

$$= 20 + 10 = 30 \text{ V}.$$

## LOSS OF ENERGY ON JOINING TWO CHARGED CONDUCTORS OR CAPACITORS

When the two charged conductors, having the capacitances $C_1$ and $C_2$, respectively, and the potentials $V_1$ and $V_2$, respectively, are connected together by the conducting wires, the charge flows from the higher potential, say, $V_1$ to the lower potential, say, $V_2$ till, finally, the potentials of the two conductors are equalised. Then, the common potential of the two conductors will be

$$V = \frac{(q_1 + q_2)}{C_1 + C_2} = \frac{(C_1V_1 + C_2V_2)}{(C_1 + C_2)}$$

The same thing, as outlined above, happens, when the two charged capacitors are connected, with the plates of the like polarities together, by the conducting wires. Before connecting together, the total energy of the charged conductors, or capacitors, is

$$U_1 = \frac{1}{2}\left(C_1V_1^2\right) + \frac{1}{2}\left(C_2V_2^2\right)$$

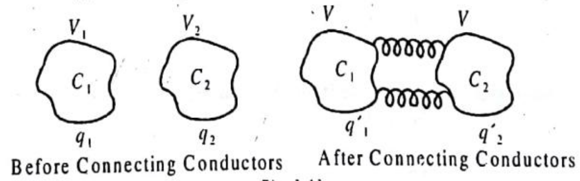



*Fig. 3.43*

After connecting together, the total energy of charged conductors, or capacitors, will be

$$U_2 = \frac{1}{2}(C_1 + C_2)V^2 = \frac{(C_1V_1 + C_2V_2)}{2(C_1 + C_2)}$$

Then, the loss of energy becomes

$$\Delta U = U_1 - U_2 = \frac{1}{2}\left(\frac{C_1C_2}{(C_1 + C_2)}\right)(V_1 - V_2)^2$$

which is mainly as the heat and also as the light and sound due to the sparking taking place. This loss is zero, when

$$V_1 = V_2$$

$$\Rightarrow \frac{q_1}{C_1} = \frac{q_2}{C_2} \Rightarrow \frac{q_1}{q_2} = \frac{C_1}{C_2}$$

i.e., the charges of the two conductors, or capacitors, before joining together are in the ratio of their capacitances. After connecting together, the charges on the two conductors, or capacitors, will also be in the ratio of their capacitancces, i.e.,

$$\frac{q_1'}{q_2'} = \frac{C_1V}{C_2V} = \frac{C_1}{C_2}$$

**ILLUSTRATION – 3.19**

A $4\mu F$ capacitor is charged by a 200V supply. It is then disconnected from the supply and then, connected to another uncharged $2\mu F$ capacitor. How much electrostatic potential energy of the first capacitor is lost in the form of heat and other radiation?

**SOLUTION :**

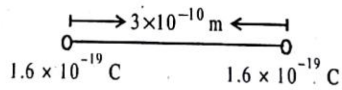
The electrostatic potential energy of the first capacitor of $4\mu F$ capacitance, lost in the form of heat and other radiation, when it is charged by a 200 $V$ supply and connected to another unchanged capacitor of $2\mu F$ capacitances after disconnection from the supply, is

$$\Delta U = \frac{1}{2}\left(\frac{C_1C_2}{C_1+C_2}\right)(V_1 \sim V_2)^2 = \frac{1}{2}\left(\frac{4\times10^{-6}\times2\times10^{-6}}{4\times10^{-6}+2\times10^{-6}}\right)(200-0)^2 = 2.67\times10^{-2}\text{J}$$

# MISCELLANEOUS SOLVED EXAMPLES

**1. Two protons in a molecule is separated by $3 \times 10^{-10}$ m. Find the electrostatic force exerted by one proton on the other.**

**Sol.**




According to Coulomb's law, the electrostatic force $F$ between two charges $q_1$ and $q_2$, which are seperated by distance $r$ is

$$F = \frac{1}{4\pi\varepsilon_0} \times \frac{q_1q_2}{r^2}$$

Here, $q_1 = q_2 = 1.6 \times 10^{-19} C, r = 3 \times 10^{-10} m$

So,

$$F = 9\times10^9 \frac{(1.6\times10^{-19})^2}{9\times10^{-20}} = 2.56\times10^{-9}\text{C} \quad \text{(Repulsive)}$$

**2. Two negative charges of unit magnitude each and a positive charge $q$ are placed along a straight line. At what position and for what value of $q$ will the system be in equilibrium? Check whether it is stable, unstable or neutral equilibrium?**

**Sol.** Let the charge + $q$ be held at a distance $x_1$ from unit negative charge at $A$, and at a distance $x_2$ from unit negative charge at $B$.

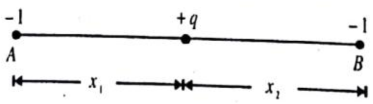



*Fig. 3.44*

For equilibrium of $q$, $\frac{q(-1)}{4\pi\varepsilon_o x_1^2} = \frac{q(-1)}{4\pi\varepsilon_o x_2^2}$

$\therefore x_1 = x_2$ i.e. q must be equidistant from $A$ and $B$.
For equilibrium of unit negative charge at B.
Force on $B$ due to charge at $A$ + force on B due to $q = 0$

$$\frac{(-1)(-1)}{4\pi\varepsilon_o(x_1+x_2)^2}+\frac{q(-1)}{4\pi\varepsilon_o x_2^2}=0$$

$$\Rightarrow \quad \frac{1}{4\pi\varepsilon_o(2x_2)^2}=\frac{-(-q)}{4\pi\varepsilon_o x_2^2} \qquad (\because x_1 = x_2)$$

$q = \frac{1}{4}$ i.e. $\frac{1}{4}$th of the magnitude of either unit charge.

Stability : If $q$ is displaced slightly towards $A$, force of attraction due to A exceeds the force of attraction due to $B$. Therefore, $q$ will get displaced further towards $A$. Hence the equilibrium of $q$ is unstable.

However, if $q$ is displaced in a direction $\perp$ to $A$, net force would bring $q$ back to its normal position. Therefore, the equilibrium will be stable.

**3. A 10 mF capacitor is charged to a potential difference of 50 V and is connected to another uncharged capacitor in parallel. Now the common potential difference becomes 20 volt. What is the capacitance of second capacitor is?**

**Sol.** $q_1 = 10\times50 = 500\ \mu C$, $C_1 = 10\mu F$, $C_2 = ?$, $q_2 = 0$

As $V = \frac{q_1+q_2}{C_1+C_2}$

$$\therefore \ C_1 + C_2 = \frac{q_1+q_2}{V} = \frac{500+0}{20} = 25\mu F$$

$C_2 = 25 - C_1 = 25 - 10 = 15\mu F$

**4. Electric force between two point charges $q$ and $Q$ at rest is $F$. Now if a charge $-q$ is placed next to $q$ what will be the (a) force on $Q$ due to $q$ (b) total force on $Q$?**

**Sol.**

(a) As electric force between two body interaction, i.e., force between two particles, is independent of presence or absence of other particles, the force between $Q$ and q will remain unchanged, i.e., $F$.

(b) An electric force is proportional to the magnitude of charges, total force on $Q$ will be given by :

$$\frac{F'}{F}=\frac{Qq'}{Qq}=\frac{q'}{q}=\frac{0}{q}=0 \qquad [\text{as } q' = q + (-q) = 0]$$

i.e., The resultant force on $Q$ will be zero.

**5. Calculate the electric field strength required to just support a water drop of mass $10^{-7}$ kg and having charge $1.6\times10^{-19}$ C.**

**Sol.** Here, $m = 10^{-7}$ kg, $q = 1.6\times10^{-19}\ C$

**Step 1 :** Let $E$ be the electric field strength required to support the water drop.
Force acting on the water drop due to electric field $E$ is

$$F = qE = 1.6\times10^{-19}\ E$$

Weight of drop acting downward,

$$W = mg = 10^{-7}\times9.8 \text{ newton.}$$

**Step 2 :** Drop will be supported if $F$ and W are equal and opposite.
i.e., $1.6\times10^{-19}\ E = 9.8\times10^{-7}$

or $$E = \frac{9.8\times10^{-7}}{1.6\times10^{-19}} = 6.125\times10^{12}\ NC^{-1}.$$

**6. The following figure shows a surface $S$ which is enclosing $-2q$ charge. The charge $+q$ is kept outside the surface $S$. Calculate the net outward/ inward flux from the surface $S$.**

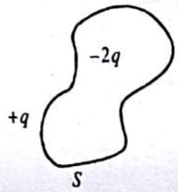



*Fig. 3.45*

**Sol.** According to Gauss law, the net flux is

$$\phi = \frac{1}{\varepsilon_0} \times \text{net charge enclosed by closed surface } = \frac{-2q}{\varepsilon_0}$$

(because $+q$ is out side the surface $S$, so net flux due to $+q$ thought $S$ is zero)

**7. In which Figure, the electric flux is maximum?**

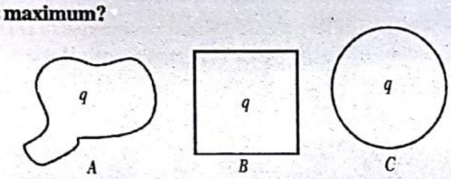



*Fig. 3.46*

**Sol.** According to Gauss Law, the electric flux linked with a closed surface depends only on net charge enclosed by that surface. It does not depend on the shape and size of that closed surface. Hence electric flux linked in above three figures are same i.e., $\phi_A = \phi_B = \phi_C$.

**8. A charge $q$ is enclosed in a cube. What is the electric flux associated with one of the faces of cube**

**Sol.** According to Gauss theorem the total electric flux

$$\phi = \frac{1}{\varepsilon_0} \times \text{total enclosed charge } = \frac{1}{\varepsilon_0} \times q.$$

Since cube has six faces. Hence electric flux linked with each face $= (1/6\phi) = q/6\varepsilon_0$.

**9. A charge $Q\,\mu C$ is placed at the centre of a cube. What will be the flux coming out from any surface will be**

**Sol.** According to Gauss's law

$$\phi \text{ ( flux from all six surfaces of cube)} = \frac{Q\,\mu C}{\varepsilon_0} = \frac{Q}{\varepsilon_o} \times 10^{-6}$$

So flux from any one of surface of cube $= \dfrac{Q}{6\varepsilon_0} \times 10^{-6}$

**10. $n$ small drops of same size are charged to $V$ volt each. If they coalese to form a single large drop, then what will be its potential?**

**Sol.** As Volume remains constant, therefore,

$$\frac{4}{3}\pi R^2 = n \times \frac{4}{3}\pi r^3 \quad \therefore \quad R = n^{1/3} r.$$

New potential $= V' = \dfrac{nq}{4\pi\varepsilon_0 R} = \dfrac{nq}{4\pi\varepsilon_0 (n^{1/3} r)} = n^{2/3} \dfrac{q}{4\pi\varepsilon_o r} = n^{2/3} V.$

# 1 EXERCISE

## Fill in the Blanks :

**DIRECTIONS :** *Complete the following statements with an appropriate word / term to be filled in the blank space(s).*

1. Electric ........... is of two types viz. positive and negative charge.
2. Proton is said to be charged .......... and electron is said to be charged ................
3. Like charges ........ and unlike charges ...............
4. A proton repels a ................ and attracts an ................
5. The force of attraction or repulsion between two .............. is given by ....................
6. Charge can neither be ................ nor .................. .
7. The charge from one body can be .................. to another body but the total charge of a system remains ................
8. The static electricity deals with electric charges at .................... and their ..........
9. Charge flows from a body at ................ to a body at ...........
10. To bring a unit positive charge from ............... to a point in an electric field, some work has to done which is called ......................
11. An electric dipole is a system of two .......... point charges
12. The capacitance of conductor depends on the .......... and .............. of conductor and the surrounding medium.
13. A system of two ...................., insulated from each other, is called a capacitor.
14. The equivalent capacitance C of the series combination is given by $\frac{1}{C}$ =................
15. The equivalent capacitance C of the parallel combination is given by C = ..................

## True / False :

**DIRECTIONS :** *Read the following statements and write your answer as true or false.*

1. The electric charge is of two types viz, positive and negative charge.
2. Like charges attracts to each other and unlike charges repels to each other.
3. A proton repels an electron.
4. A nutron repels a proton.
5. Charge can neither be created nor destroyed.
6. Proton is said to be charged positively and electron is said to be charged negatively.
7. The branch of electricity which deals with the properties of electrified bodies due to a moving charge is called electrostatics.
8. In nature charge (Q) always occurs as an integral multiple of electronic charge 'e' i.e. Q = ne, where n = 1, 2, 3, ..........
9. Charge can be in fraction of e, i.e. 1.7e, 0.8e, or –1.3e.
10. The electronic charge 'e' is the maximum possible charge.
11. The device used to detect the presences of charge and to Identify the nature of charge on a body, is called an electroscop.
12. An electric dipole is a pair of equal and same charges.
13. The mutual electrostatic force between two point charges $q_1$ and $q_2$ is inversely proportional to the product of charges $q$, $q_2$.
14. Electric field due to a point charge $q$ has a magnitude $\frac{|q|}{4\pi\varepsilon_0 r^3}$.
15. Potential at a point is the force due to electric dipole.
16. For capacitors in the series combination, the total capacitance $C$ is given by $C = C_1 + C_2 + C_3 + ............$

## Match the Following :

**DIRECTIONS :** *Each question contains statements given in two columns which have to be matched. Statements (A, B, C, D) in column I have to be matched with statements (p, q, r, s) in column II.*

1.

| Column I | Column II |
|---|---|
| (A) Like charges repels and unlike attracts. | (p) Dr. William Gilbert |
| (B) Numerical value of force between two charges | (q) Thomos Brown |
| (C) Methods of charging | (r) Coulomb by (torsion balance) |
| (D) Amount of induced charge | (s) Faraday ice pail exp. |

2.

| Column I | Column II |
|---|---|
| (A) e/m of electron | (p) J.J. Thomson |
| (B) Charge and mass (indirectly) of electron and quanta of charge. | (q) R.A. millikan (by oil drop exp.) |
| (C) Concept of line of force | (r) M. Faraday |
| (D) Highest common factor method | (s) Max Plank |

3. Two point charges Q and –Q/4 are separated by L

| Column I | Column II |
|---|---|
| (A) Zero potential | (p) L/3 on right side of charge –Q/4 |
| (B) Zero electric field | (q) L/5 on left side of charge –Q/5 |
| (C) Infinite potential | (r) L on right side of charge –Q/4 |
| (D) Infinite electric field | (s) Near charge Q. |

## VSAQ Very Short Answer Questions :

**DIRECTIONS :** *Give answer in one word or one sentence.*

1. Write the physical quantity which has its unit coulomb/volt? Is it a vector or a scalar quantity?
2. Write down the relation between electric field and potential at a point.
3. Is electrostatic potential necessarily zero at a point where electric field strength is zero?

   Illustrate your answer.
4. What is the workdone in moving a charge of 50 nC between two points on an equipotential surface?
5. Draw an equipotential surface in a uniform electric field.
6. What is the ratio of electric field intensities at any two points between the plates of a parallel plate capacitor?
7. The work done in moving a charge of 3C between two points is 6J. What is the potential difference between the points?
8. In a parallel plate capacitor, the capacitance increases from 4μF to 80 μF, on introducing a dielectric medium between the plates. What is the dielectric constant of the medium?
9. The equivalent capacitance of the combination between A and B in the given figure is 15 μF. Calculate the capacitance of capacitor *C*.


10. Two large conducting spheres carrying charges $Q_1$ and $Q_2$ are brought close to each other. Is the magnitude of electrostatic force between them exactly given by $Q_1Q_2/4\pi\varepsilon_0 r^2$, where $r$ is the distance between their centres?
11. If Coulomb's law involved $1/r^1$ dependence (instead of $1/r^2$), would Gauss's law be still true?
12. A small test charge is released at rest at a point in an electrostatic field configuration. Will it travel along the field line passing through that point?
13. We know that electric field is discontinuous across the surface of a charged conductor. Is electric potential also discontinuous there?
14. What meaning would you give to the capacitance of a single conductor?
15. What meaning would you give to the capacitance of a single conductor?
16. Name the physical quantity whose SI unit is (a) newton/coulomb, (b) joule/coulomb.
17. What orientation of an electric dipole in a uniform electric field corresponds to its stable equilibrium?
18. Calculate the no. of electrons in 1C charge.
19. Draw lines of force to represent a uniform electric field.
20. Which particles are responsible for the flow of current in conductors?
21. What is the SI unit of electric potential?
22. Write the mathematical expression for electric potential.

## SQA Short Answer Questions :

**DIRECTIONS :** *Give answer in 2-3 sentences.*

1. Two point electric charges of unknown magnitude and sign are placed at a distance '*d*' apart. The electric field intensity is zero at a point, not between the charges but on the line joining them. Write two essential conditions for this to happen.
2. Electric charge is distributed uniformly on the surface of a spherical rubber balloon. Show how the value of electric intensity vary (i) on the surface (ii) inside and (iii) outside?
3. A surface encloses an electric quadrupole. What is the total electric flux through the surface?
4. What is the force between two small charged spheres having charges of $2 \times 10^{-7}$C and $3 \times 10^{-7}$ placed 30 cm apart in air?
5. When a glass rod is rubbed with a silk cloth, charges appear on both. A similar phenomenon is observed with many other pairs of bodies. Explain how this observation is consistent with the law of conservation of charge.
6. (a) An electrostatic field line is a continuous curve. That is, a field line cannot have sudden breaks. Why not?
   (b) Explain why two field lines never cross each other at any point?
7. Three capacitors each of capacitance 9pF are connected in series. (a) What is the total capacitance of the combination? (b) What is the potential difference across each capacitor, if the combination is connected to a 120 V supply?
8. Calculate the value of *C* in the following combination if the equivalent capacitance between *P* and *Q* is 30 μF.

9. What is an equipotential surface? Show that the electric field is always directed perpendicular to an equipotential surface.
10. Equipotential surfaces are perpendicular to field lines. Why?
11. Distinguish between electric potential and potential energy.
12. Is it possible for a metal sphere of 1 cm radius to hold a charge of 1C?
13. What is the relation between dielectric constant and electric susceptibility?
14. An electric dipole is free to move in a uniform electric field. Explain its motion when it is placed (i) parallel to the field and (ii) perpendicular to the field.
15. Two capacitors of capacitances $C_1 = 3\ \mu F$ and $C_2 = 6\ \mu F$ arranged in series are connected in parallel with a 3rd capacitor $C_3 = 4\ \mu F$. The total arrangement is connected to a 6V battery. Calculate the total energy stored is the capacitors.

## LAQ Long Answer Questions :

**DIRECTIONS :** *Give answer in four to five sentences.*

1. (a) Explain the meaning of the statement 'electric charge of a body is quantised'.
   (b) Why can one ignore quantisation of electric charge when dealing with macroscopic i.e., large scale charge?
2. A capacitor is charged to potential $V_1$. The power supply is then disconnected and the capacitor is then connected in parallel to another capacitor of potential $V_2$.
   Derive an expression for the common potential of the combination of capacitor.
3. Derive the expression for the capacitance of a parallel plate capacitor filled with dielectric.
4. How is Coulomb's law similar to Newton's law of gravitation? How is it different?
5. How does the magnitude of electric force compare with the charge between a pair of charged particles when they are brought to half their original distance of separation? To One-quarter their original distance? To four times their original distance? (What law guides your answers?)

# 2 EXERCISE

## MCQ Multiple Choice Questions

**DIRECTIONS :** *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONLY ONE is correct.*

1. An electric dipole, consisting of two opposite charges of $2\times10^{-6}$ C each separated by a distance 3 cm is placed in an electric field of $2\times10^{5}$ N/C. Torque acting on the dipole is
   (a) $12\times10^{-1}$ N – m (b) $12\times10^{-2}$ N – m
   (c) $12\times10^{-3}$ N – m (d) $12\times10^{-4}$ N – m
2. If the potential of a capacitor having capacity 6 $\mu F$ is increased from 10 V to 20 V, then increase in its energy will be
   (a) $4\times10^{-4}$ J (b) $4\times10^{-6}$ J
   (c) $9\times10^{-4}$ J (d) $12\times10^{-6}$ J
3. Intensity of an electric field (E) depends on distance $r$, due to a dipole, is related as
   (a) $E\propto\frac{1}{r}$ (b) $E\propto\frac{1}{r^2}$
   (c) $E\propto\frac{1}{r^3}$ (d) $E\propto\frac{1}{r^4}$
4. A charge q is placed at the centre of the line joining two exactly equal positive charges $Q$. The system of three charges will be in equilibrium, if q is equal to
   (a) $-\frac{Q}{4}$ (b) $+Q$
   (c) $-Q$ (d) $\frac{Q}{2}$
5. The formation of a dipole is due to two equal and unlike point charges placed at a
   (a) short distance (b) long distance
   (c) above each other (d) none of these
6. A parallel plate condenser with oil between the plates (dielectric constant of oil $K = 2$) has a capacitance $C$. If the oil is removed, then capacitance of the capacitor becomes
   (a) $\sqrt{2}C$ (b) $2C$ (c) $\frac{C}{\sqrt{2}}$ (d) $\frac{C}{2}$
7. When air is replaced by a dielectric medium of force constant $K$, the maximum force of attraction between two charges, separated by a distance
   (a) decreases $K$-times (b) increases $K$-times
   (c) remains unchanged (d) becomes $\frac{1}{K^2}$ times

**8.** A capacitor is charged to store an energy U. The charging battery is disconnected. An identical capacitor is now connected to the first capacitor in parallel. The energy in each of the capacitors is
(a) $U/2$ (b) $3U/2$
(c) $U$ (d) $U/4$

**9.** A charge $Q$ is placed at the corner of a cube. The electric flux through all the six faces of the cube is
(a) $Q/3\varepsilon_0$ (b) $Q/6\varepsilon_0$
(c) $Q/8\varepsilon_0$ (d) $Q/\varepsilon_0$

**10.** In a parallel plate capacitor, the distance between the plates is d and potential difference across the plates is $V$. Energy stored per unit volume between the plates of capacitor is
(a) $\frac{Q^2}{2V^2}$ (b) $\frac{1}{2}\varepsilon_0\frac{V^2}{d^2}$
(c) $\frac{1}{2}\frac{V^2}{\varepsilon_0 d^2}$ (d) $\frac{1}{2}\varepsilon_0\frac{V^2}{d}$

**11.** Energy stored in a capacitor is
(a) $\frac{1}{2}QV$ (b) $QV$
(c) $\frac{1}{QV}$ (d) $\frac{2}{QV}$

**12.** Three capacitors each of capacity $4\mu F$ are to be connected in such a way that the effective capacitance is $6\ \mu F$. This can be done by
(a) connecting two in parallel and one in series
(b) connecting all of them in series
(c) connecting them in parallel
(d) connecting two in series and one in parallel

**13.** When a body is charged by induction, then the body
(a) becomes neutral
(b) does not lose any charge
(c) loses whole of the charge on it
(d) loses part of the charge on it

**14.** If a body is positively charged, then it has
(a) excess of electrons (b) excess of protons
(c) deficiency of electrons (d) deficiency of neutrons

**15.** On charging by conduction, mass of a body may
(a) increase (b) decreases
(c) increase or decrease (d) none

**16.** Coulomb's law is true for
(a) atomic distances ($= 10^{-11}\ m$)
(b) nuclear distances ($= 10^{-15}\ m$)
(c) charged as well as uncharged particles
(d) all the distances

**17.** Two charges are placed a certain distance apart. A metallic sheet is placed between them. What will happen to the force between the charges?
(a) increase (b) decrease
(c) remains unchanged (d) either 'a' or 'b'

**18.** Which of the following is best insulator?
(a) Carbon (b) Paper
(c) Graphite (d) Ebonite

**19.** Two spheres A and B of exactly same mass are given equal positive and negative charges respectively. Their masses after charging
(a) remains unaffected (b) mass of A > mass of B
(c) mass of A < mass of B (d) nothing can be said

**20.** What happens when some charge is placed on a soap bubble?
(a) its radius decreases (b) its radius increases
(c) the bubble collapses (d) none of the above

**21.** Quantisation of charge implies
(a) charge cannot be destroyed
(b) charge exists on particles
(c) there is a minimum permissible charge on a particle
(d) charge, which is a fraction of a coulomb is not possible.

**22.** Two charges are placed a certain distance apart in air. If a glass slab is introduced between them, the force between them will
(a) increase (b) decrease
(c) remains the same (d) be zero

**23.** A charge $q_1$ exerts some force on a second charge $q_2$. If third charge $q_3$ is brought near, the force of $q_1$ exerted on $q_2$
(a) decreases
(b) increases
(c) remains unchanged
(d) increases if $q_3$ is of same sign as $q_1$ and decreases if $q_3$ is of opposite sign.

**24.** A positively charged rod is brought near an uncharged conductor. If the rod is then suddenly withdrawn, the charge left on the conductor will be
(a) positive (b) negative
(c) zero (d) not sure

**25.** The ratio of electric force between two electrons to two protons separated by the same distance in air is
(a) $10^0$ (b) $10^6$
(c) $10^4$ (d) none

**26.** The dielectric constant of a metal is
(a) $\infty$ (b) 0
(c) 1 (d) none

**27.** A metallic particle having no net charge is placed near a finite metal plate carrying a positive charge. The electric force on the particle will be
(a) towards the plate (b) away from the plate
(c) parallel to the plate (d) zero

**28.** If a body is charged by rubbing it, its weight
(a) remains precisely constant
(b) increases slightly
(c) decreases slightly
(d) may increase slightly or may decrease slightly

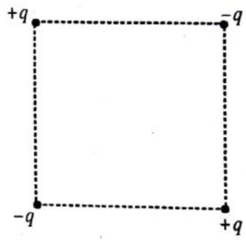
**29.** An electric field can deflect
(a) neutrons (b) X-rays
(c) $\gamma$-rays (d) $\alpha$-particles

30. A hollow sphere of charge does not have electric field at
   (a) outer point (b) interior point
   (c) beyond 2 m (d) beyond 100 m
31. If one penetrates a uniformly charged solid sphere, the electric field E
   (a) increases
   (b) decreases
   (c) is zero at all points
   (d) remains same as at the surface
32. If one penetrates a uniformly charged spherical cloud, electric field strength
   (a) decreases directly as the distance from the centre
   (b) increases directly as the distance from the centre
   (c) remains constant
   (d) none of the above
33. Electric lines of force about a negative point charge are
   (a) circular anticlockwise (b) circular clockwise
   (c) radial, inwards (d) radial, outwards
34. Electric lines of force
   (a) exist everywhere
   (b) exist only in the immediate vicinity of electric charges
   (c) exist only when both positive and negative charges are near one another
   (d) are imaginary
35. Debye is the unit of
   (a) electric flux (b) electric dipole moment
   (c) electric potential (d) electric field intensity
36. An electric dipole will experience a net force when it is placed in
   (a) a uniform electric field
   (b) a non-uniform electric field
   (c) both the above cases
   (d) none of these
37. An electric dipole is kept in a uniform electric field. it experiences
   (a) a force and a torque
   (b) a force, but no torque
   (c) A torque but no force
   (d) neither a force nor a torque
38. A charge $q$ is enclosed in a cube. What is the electric flux associated with one of the faces of cube
   (a) $q/\varepsilon_0$ (b) $\varepsilon_0/q$
   (c) $6q/\varepsilon_0$ (d) $q/6\varepsilon_0$
39. A charge Q is placed at the corner of a cube. The electric flux through all the faces of the cube is
   (a) $Q/\varepsilon_0$ (b) $Q/6\varepsilon_0$
   (c) $Q/8\varepsilon_0$ (d) $Q/3\varepsilon_0$
40. Positive electric flux indicates that electric lines of force are directed
   (a) outwards (b) inwards
   (c) outwards or inwards (d) none of these
41. Electric flux at a point in an electric field is
   (a) positive (b) negative
   (c) zero (d) none of these
42. Electric flux over a surface in an electric field may be
   (a) positive (b) negative
   (c) zero (d) positive, negative, zero
43. The electric potential at a point on the equatorial line of an electric dipole is
   (a) directly proportional to distance
   (b) inversely proportional to distance
   (c) inversely proportional to square of the distance
   (d) none of the above

## MTOC More than One Correct :

**DIRECTIONS :** *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONE OR MORE may be correct.*

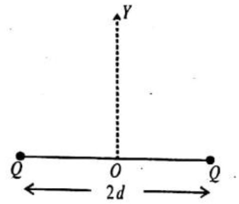
1. Four electric charges are arranged as shown in the figure at the four corners of a square of side a. The potential energy of the system is:




   (a) zero (b) negative
   (c) positive (d) greater than $\frac{1}{4\pi\varepsilon_0}\frac{2q^2}{a}$
   (e) less than $\frac{1}{4\pi\varepsilon_0}\left(-\frac{2q^2}{a}\right)$
2. Three charged particles are in equilibrium under their electrostatic forces only:
   (a) the particles must be collinear
   (b) all the charges cannot have the same magnitude
   (c) all the charges cannot have the same sign
   (d) the equilibrium is unstable
3. Inside a uniformly charged spherical conductor, the electric:
   (a) potential is zero everywhere
   (b) potential is non-zero and same everywhere
   (c) field is zero everywhere
   (d) field has the same magnitude everywhere but it is not zero

4. Four charges, all of the same magnitude are placed at the four corners of a square. At centre of the square, the potential is $V$ and the field is $E$. By suitable choices of the signs of four charges, which of the following can be obtained?
(a) $V=0, E=0$ (b) $V=0, E\neq 0$
(c) $V\neq 0, E=0$ (d) $V\neq 0, E\neq 0$

5. Consider two identical charges placed at a distance 2d apart as shown in the figure. The equilibrium of a positive test charge placed at the point $O$ midway between them may be:




(a) neutral
(b) stable for displacement along the $x$-axis
(c) stable for displacement along the $y$-axis
(d) unstable for displacement along the $x$-axis

6. Across the surface of a charged conductor, the electric:
(a) field is continuous (b) potential is continuous
(c) field is discontinuous (d) potential is discontinuous

7. A point charge is brought in an electric field. The electric field at a nearby point:
(a) will increase if the charge is positive
(b) will decrease if the charge is negative
(c) may increase if the charge is positive
(d) may decrease if the charge is negative

8. Which of the following quantities do not depend on the choice of zero potential or zero potential energy?
(a) Potential at a point
(b) Potential difference between the points
(c) Potential energy of a two charge system
(d) Change in potential energy of a two charge system

9. An electric dipole is placed at the centre of a sphere. Mark the correct option:
(a) the flux of the electric field through the sphere is zero
(b) the electric field is zero at every point of the sphere
(c) the electric field is not zero anywhere on the sphere
(d) the electric field is zero on a circle on the sphere

10. In a uniform electric field, equipotential surfaces must:
(a) be plane surfaces
(b) be normal to the direction of the field
(c) be placed such that surfaces having equal differences in potential are separated by equal distances
(d) have decreasing potentials in the direction of the field

11. $S_1$ and $S_2$ are two equipotential surfaces on which the potentials are not equal:
(a) $S_1$ and $S_2$ both cannot intersect
(b) $S_1$ and $S_2$ both cannot be plane surfaces
(c) in the region between $S_1$ and $S_2$, the field is maximum where they are closest to each other
(d) a line of force from $S_1$ to $S_2$ must be perpendicular to both

12. Which of the following is/are proportional to the inverse square of the distance $x$?
(a) The potential at a distance $x$ from an isolated point charge
(b) The electric field at a distance x from an isolated point charge
(c) The force per unit length between two thin, straight, infinitely long current carrying conductors, parallel to each other, separated by a distance $x$
(d) The gravitational attraction between two small bodies kept at a distance $x$ apart

13. A positive charge Q is placed at the centre of a thin metallic spherical shell. Select the correct statements from the following:
(a) the electric field at any point outside the shell is zero
(b) the electrostatic potential at any point outside the shell is $Q/4\pi\varepsilon_1 r$, where $r$ is the distance of the point from O
(c) the outer surface of the spherical shell is an equipotential shell
(d) the electric field at any point inside the shell, other than $O$. is zero

14. A parallel plate capacitor is charged to a definite potential and the charging battery is disconnected. Now if the plates of capacitor are moved apart, then:
(a) the stored energy of the capacitor increases
(b) charge on the capacitor increases
(c) voltage of the capacitor increases
(d) the capacitance increases

15. A capacitor of capacity 100 μF is discharged through a resistance of 1000 ohm:
(a) its time constant is $1 \times 10^{-1}$ s
(b) during time $0.693 \times 10^{-1}$ s, the charge left on the capacitor is half of its maximum charge
(c) during its time constant charge left on the capacitor is 0.63 times to its maximum charge
(d) during its time constant, charge left on the capacitor is 0.37 times to its maximum charge

16. Two parallel plate capacitors are constructed one by a pair of iron plates and the second by a pair of copper plates of same area and same spacings. Then:
(a) the copper plate capacitor has a greater capacitance than the iron one
(b) both capacitors have equal, non-zero capacitances in the uncharged state
(c) both capacitors will have equal capacitances only if they are charged equally
(d) the capacitances of the two capacitors are equal even if they are unequally charged

17. Mark the correct statements?
(a) A given conducting sphere can be charged to any extent.
(b) A given conducting sphere cannot be charged to a potential greater than a certain value.
(c) A given conducting sphere cannot be charged to a potential less than a certain minimum value.
(d) None of the above

## FIP Fill in the Passage :

**DIRECTIONS :** *Fill in the blanks in the following passage(s) from the words given inside the box.*

**I.** | Friction electrons transferring Negative charge Positive charge |

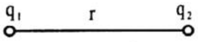
Electric charge is developed due to actual transfer of .......1....... When two substances are rubbed against each other, energy is provided from outside to overcome .......2....... between them. This energy is used to remove electrons from one substance and .......3....... them to the other. The transfer takes place from the material in which electrons are held less tightly to the material in which electrons are held more tightly. The material which loses electrons acquires .......4....... and which gains electrons acquires an equal .......5.......

**II.** | multiple +ne, integral number electron quantization ± e. |

Any charge exists in discrete lumps or packets of a certain minimum charge .......1....... where e is the charge of an electron. According to .......2....... of charge, the charge on a body can be only an integral .......3....... of charge on the .......4....... i.e., q = .......5.......where n = 1, 2, 3 ....... and e = $1.6 \times 10^{-19}$ C The cause of quantization is that only .......6....... of electrons can be transferred from a body to the other on rubbing.

**III.** | $q_1q_2$ Permittivity directly $r^2$ inversely |

The force of interaction between any two point charges is .......1....... proportional to the product of the charges and .......2....... proportional to the square of the distance between them.




Mathematically, $F \propto$ .......3.......

and $F \propto \frac{1}{r^2}$

$\therefore$ $F \propto \frac{q_1 q_2}{.......4.......}$

$\therefore$ $F = k\frac{q_1 q_2}{r^2}$

where, k = electrostatic force constant

$= \frac{1}{4\pi\varepsilon_0}$ in free space $= \frac{1}{4\pi\varepsilon}$ in any medium

where, $\varepsilon$ is the absolute electric .......5....... of the medium and $\varepsilon_0$ is the absolute electric permittivity of free space or vacuum.

$\therefore$ $F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$ and $F_m = \frac{1}{4\pi\varepsilon}\frac{q_1 q_2}{r^2}$ are forces between two charges $q_1$ and $q_2$ separated by a distance 'r' in free space and a medium respectively.

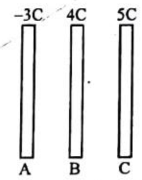
Dividing we get, $\frac{F}{F_m} = \frac{\varepsilon}{\varepsilon_0} = \varepsilon_r$ or $k$ ; where $\varepsilon_r$ is called relative permittivity or k is called dielectric constant or specific inductive capacity.

## PBQ Passage Based Questions :

**DIRECTIONS :** *Study the given paragraph(s) and answer the following questions.*

### Passage – I

Three large plates A, B and C are placed parallel to each other and charges are given as shown.



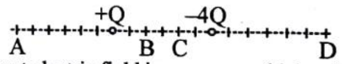

**1.** The charge that appears on the left surface of plate B is:
(a) 5C (b) 6C
(c) 3C (d) –3C

**2.** The charge on inner surface of plate C, if plate B is earthed,
(a) 5C (b) 6C
(c) 3C (d) –3C

**3.** The charge on left surface of B, if B and C both are earthed,
(a) 5C (b) 6C
(c) 3C (d) –3C

### Passage – II

Related to the following diagram of two charges, +Q and –4Q.




**1.** The net electric field is zero near which point?
(a) A (b) B
(c) C (d) D

**2.** At which point does the net electric field vector point to the left?
(a) A (b) B
(c) C (d) D

**3.** At which point would a small positive charge q feel the greatest force?
(a) A (b) B
(c) C (d) D

### Passage – III

Two fixed charges –2 Q and Q are located at the points with coordinates (–3 *a*, 0) and (+ 3 *a*, 0) respectively in the *X–Y* plane.

**1.** All the points in the *X–Y* plane where the electric potential due to the two charges is zero, lie on a;
(a) straight line (b) circle
(c) parabola (d) ellipse

**2.** The expression for the potential *V*(*x*) at a general point on the *x*-axis is given by:

(a) $V(x) = \frac{1}{4\pi\varepsilon_0}\left[\frac{Q}{3a-x} - \frac{2Q}{(3a+x)}\right]$ for $0 < x < 3a$

(b) $V(x) = \frac{1}{4\pi\varepsilon_0}\left[\frac{2Q}{3a-x} - \frac{Q}{(3a+x)}\right]$ for $0 < x < 3a$

(c) $V(x) = \frac{1}{4\pi\varepsilon_0}\left[\frac{Q}{3a+x} - \frac{2Q}{(3a-x)}\right]$ for $0 < x < 3a$

(d) $V(x) = \frac{1}{4\pi\varepsilon_0}\left[\frac{Q}{3a-x} + \frac{2Q}{(3a+x)}\right]$ for $0 < x < 3a$

## A&R Assertion & Reason :

**DIRECTIONS :** *Each of these questions contains an Assertion followed by Reason. Read them carefully and answer the question on the basis of following options. You have to select the one that best describes the two statements.*

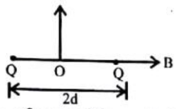
(a) If both **Assertion** and **Reason** are **correct** and Reason is the **correct explanation** of Assertion.

(b) If both **Assertion** and **Reason** are correct, but Reason is **not the correct explanation** of Assertion.

(c) If **Assertion** is **correct** but **Reason** is **incorrect**.

(d) If **Assertion** is **incorrect** but **Reason** is **correct**.

1. **Assertion :** Consider two identical charges placed distance 2d apart, along $x$-axis.

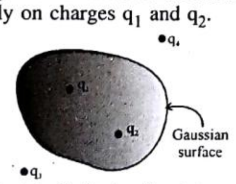



The equilibrium of a positive test charge placed at the point O midway between them is stable for displacements along the x-axis.

**Reason:** Force on test charge is zero.

2. **Assertion :** A deuteron and an $\alpha$-particle are placed in an electric field. If $F_1$ and $F_2$ be the forces acting on them and $a_1$ and $a_2$ be their accelerations respectively then, $a_1 = a_2$.
**Reason :** Forces will be same in electric field.

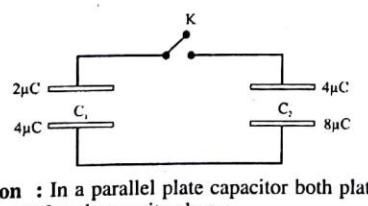
3. **Assertion :** Four point charges $q_1$, $q_2$, $q_3$ and $q_4$ are as shown in figure. The flux over the shown Gaussian surface depends only on charges $q_1$ and $q_2$.




**Reason :** Electric field at all points on Gaussian surface depends only on charges $q_1$ and $q_2$.

4. **Assertion :** The positive charge particle is placed in front of a spherical uncharged conductor. The number of lines of forces terminating on the sphere will be more than those emerging from it.
**Reason :** The surface charge density at a point on the sphere nearest to the point charge will be negative and maximum in magnitude compared to other points on the sphere.

5. **Assertion :** Charges are given to plates of two plane parallel plate capacitors $C_1$ and $C_2$ (such that $C_2 = 2C_1$) as shown in figure. Then the key K is pressed to complete the circuit. Finally the net charge on upper plate and net charge the circuit. Finally the net charge on upper plate and net charge on lower plate of capacitor $C_1$ is positive.




**Reason :** In a parallel plate capacitor both plates always carry equal and opposite charge.

6. **Assertion :** Each of the plates of a parallel-plate capacitor is given equal positive charge Q. The charges on the facing surfaces will be same.
**Reason :** A negative charge (–Q) will be induced on each of the facing surfaces.

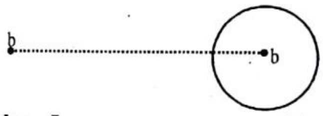
7. **Assertion :** Electric potential and electric potential energy are different quantities.
**Reason :** For a system of positive test charge and point charge electric potential energy = electric potential.

8. **Assertion :** Two equipotential surfaces cannot cut each other.
**Reason :** Two equipotential surfaces are parallel to each other.

## MMQ Multiple Matching Questions :

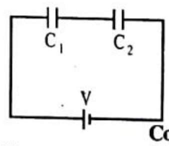
**DIRECTIONS :** *Each question has four statements (A, B, C and D) given in Column I and five statements (p, q, r, s and t) in Column II. Any given statement in Column I can have correct matching with one or more statement(s) given in Column II. Match the entries in column I with entries in column II.*

1. For the situation shown in the figure below, match the entries of column I with the entries of column II.



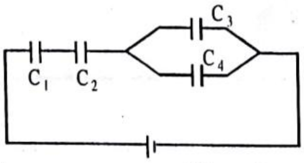

| Column I | Column II |
|---|---|
| (A) If we displace the inside charge | (p) distribution of charge on the inner surface of conductor is uniform |
| (B) If we displace the outside charge | (q) distribution of charge on the inner surface of conductor is nonuniform |
| (C) In ths situation shown | (r) distribution of charge on the outer surface of conductor is uniform |
| (D) If outside charge is not present | (s) distribution of charge on the outer surface of conductor is nonuniform |

2. In the circuit shown in figure, plates of capacitor $C_1$ are gradually pulled apart. Then, match the entries of column I with the entries of column II.



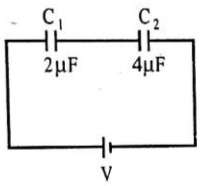

| Column I | Column II |
|---|---|
| (A) Potential difference across $C_2$. | (p) will increase |
| (B) Charge on $C_2$ | (q) will decrease |
| (C) Potential energy stored in $C_2$ | (r) will remain same |
| (D) Electric field between plates of $C_1$ | |

3. In the circuit shown in the following figure, $C_1 = C, C_2 = 2C$, $C_3 = 3C, C_4 = 4C$. Match the entries of column I with the entries of column II.




| Column I | Column II |
|---|---|
| (A) Maximum potential difference | (p) across $C_1$ |
| (B) Minimum potential difference | (q) across $C_2$ |
| (C) Maximum potential energy | (r) across $C_3$ |
| (D) Minimum potential energy | (s) across $C_4$ |

4. In the given figure, the separation between the plates of $C_1$ is slowly increased to double of its initial value, then match the following.




| Column I | Column II |
|---|---|
| (A) The potential difference across $C_1$ | (p) increases |
| (B) The potential difference across $C_2$ | (q) decreases |
| (C) The energy stored in $C_1$ | (r) increases by a factor of 6/5 |
| (D) The energy stored in $C_2$ | (s) decreases by a factor of 18/25 |

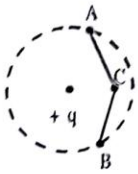
5. Match the entries of colun I with the entries of column II.

| Column I | Column II |
|---|---|
| (A) When a dielectric slab is gradually inserted between the plates of an isolated parallel plate capacitor | (p) The electric potential energy of the system decreases |
| (B) When a dielectric slab is gradully inserted between the plates of a parallel plate capacitor and its potential is kept constant | (q) Work done by external agent is positive |
| (C) When the plates of a parallel plate capacitor are pulled apart, keeping its potential constant | (r) Work done by battery is positive |
| (D) When the plates of a parallel plate capacitor are pulled apart, keeping its charge constant. | (s) Work done by external agent is negative |

## HOTS *Subjective Questions :*

**DIRECTIONS :** *Answer the following questions.*

1. If a point charge +q, is taken first from A to C, then from C to B of a circle drawn with another point charge +q at centre, then along which path more work will be done?




2. Find the electric field between two metal plates 3 mm apart, connected to a 12 V battery.
3. Calculate the electric potential at the surface of a gold nucleus. Given, the radius of the nucleus = $6.6 \times 10^{-15}$ m and atomic number of gold = 79.
4. Calculate the potential at a point P due to a charge of $4 \times 10^{-7}$ C located 10 cm away.
5. At a point due to a point charge, the values of electric field intensity and potential are 32 N/C and 16 J/C respectively. Calculate magnitude of charges and distance of charge from the point of observation.
6. A parallel plate capacitor with air has a capacitance of 10 μF. If the distance between the plates is reduced to half and the space between them is filled with a material of dielectric constant 10, find the new capacitance.
7. Each plate of a parallel plate capacitor has an area of $6 \times 10^{-3}$ m$^2$ and the distance between the plates is 3mm. Calculate the capacitance of the capacitor with air as dielectric. If this capacitor is connected to a 200 V supply, what is the change on each plate of the capacitor?
8. A given charge situated at a distance from an electric dipole in the end on position, experiences a force *F*. If the distance of charge is doubled, what will the force acting on the charge?
9. In a parallel plate capacitor the potential difference of $10^2$ V is maintained between the plates. What will be the electric field at points A and B?
10. Two protons A and B are placed between two parallel plates having a potential difference of V as shown in the figure. Will these proton experience equal or unequal force ?
11. A and B are two conducting spheres of the same radius. A being solid and B hollow, both are charged to the same potential. What will be the relation between the charges on the two spheres?
12. How much energy will be stored by a capacitor of 470 μF when charged by a battery of 20 V?
13. How does the force between two point charges change if the dielectric constant of the medium in which they are kept increases?
14. Is electrostatic potential a scalar quantity or a vector quantity?

# SOLUTIONS

Brief Explanations of Selected Questions

## Exercise 1

### FILL IN THE BLANKS :

1. (charge)
2. (positively, Negatively)
3. (repuls, attract)
4. (proton/electron)
5. (charges, Coulomb's law)
6. (created, destroyed)
7. (transferred, constant)
8. (rest, effects)
9. (higher potential, lower potential)
10. infinity, electric potential
11. unlike
12. shape, size
13. Conductors
14. $\left(\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}+.............\right)$
15. $(C_1+C_2+C_3\ ................)$

### TRUE / FALSE

| | | | | | |
|---|---|---|---|---|---|
| 1. | True | 2. | False | 3. | False |
| 4. | False | 5. | True | 6. | True |
| 7. | False | 8. | True | 9. | False |
| 10. | False | 11. | True | 12. | False |
| 13. | False | 14. | False | 15. | False |
| 16. | False | | | | |

### MULTIPLE MATCHING QUESTIONS :

1. (A) $\to$ p; (B) $\to$ r; (C) $\to$ q; (D) $\to$ s
2. (A) $\to$ p; (B) $\to$ q; (C) $\to$ r; (D) $\to$ s
3. (A) $\to$ p,q; (B) $\to$ r; (C) $\to$ s; (D) $\to$ s

### VERY SHORT ANSWER QUESTIONS :

1. The quantity is capacitance $\left(C=\frac{Q}{V}\right)$. It is a scalar quantity.

2. $E=-\frac{dV}{dr}$

   i.e. electric field at a point is the negative of the electric potential gradient at that point.

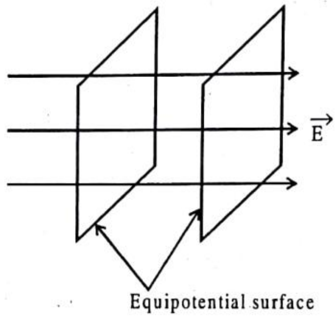
3. No, it is not necessary.

   $\because\ E=-\frac{dV}{dr}$

   $\therefore$ If V is constant, E will be zero.

   Ex: The electric field inside a hollow spherical conductor is zero but potential is not zero.

4. Workdone to move the charge 50 nC on the equipotential surface is zero as the potential at every point is same.

5. 


   It is a plane surface perpendicular to the electric field.

6. Required ratio is 1 : 1, since the electric field is uniform between the plates of a capacitor.

7. $V=\frac{W}{q}=\frac{6}{3}=2V.$

8. $C=\frac{\varepsilon_0 A}{d}$ and $C'=\frac{k\varepsilon_0 A}{d}$

   $\therefore\ \frac{C'}{C}=k \Rightarrow k=\frac{80}{4}=20$

9. C and 20 $\mu$F are in series.

   $C_{eq}=15\ \mu F$

   $\therefore\ \frac{1}{15}=\frac{1}{20}+\frac{1}{C} \Rightarrow \frac{1}{C}=\frac{1}{15}-\frac{1}{20}$

   $\Rightarrow \frac{1}{C}=\frac{4-3}{60}=\frac{1}{60} \Rightarrow C=60\ \mu F.$

10. No, because charge distributions on the spheres will not be uniform.
11. No.
12. Not necessarily. (True only if the field line is a straight line.) The field line gives the direction of acceleration, not that of velocity, in general.
13. No, potential is continuous.
14. A single conductor is a capacitor with one of the 'plates' at infinity.
15. A water molecule has permanent dipole moment. However, detailed explanation of the value of dielectric constant requires microscopic theory and is beyond the scope of the book.

**16.** Newton/coulomb is the SI unit of electric field strength.

(b) Joule/coulomb is the SI unit of electric potentials.

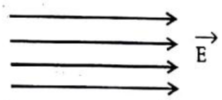
$\therefore$ Force will decrease as k increases.

**17.** If the dipole is placed along the direction of the field, its equilibrium is stable $(\theta = 0°)$.

**18.** $1e = 1.6 \times 10^{-19}$ C

$\therefore$ No. of electrons $= \dfrac{1}{1.6\times10^{-19}} = 6.25 \times 10^{18}$

**19.**




**20.** Electrons.

**21.** In SI, electric potential is measured in volt (V).

**22.** Mathematically, electric potential is written as

$$V = \frac{W}{q}$$

**SHORT ANSWER QUESTIONS :**

**1.** (a) The two charges are of opposite sign so that force will be attractive in nature.

(b) The two charges have different magnitudes – the charge of smaller magnitude will be nearer to the point where the total field intensity is zero.

**2.** (i) On the surface, E = constant

(ii) Inside the surface, E = 0.

(iii) Out side the surface, $E \propto \dfrac{1}{r^2}$.

**3.** An electric quadrupole consists of the two electric dipoles, each one having the two point charges +q, –q and the zero net charge. Therefore, the net charge of a quadrupole is zero and, then, according to the Gauss's Law, the total electric flux through the surface enclosing the quadrupole, given by the net charge inside of the surface divided by the permittivity $\varepsilon_0$, is zero.

**4.** Given, $q_1 = 2 \times 10^{-7}$C, $q_2 = 3 \times 10^{-7}$C, r = 30 cm = 0.3 m, F = ?

By Formula, $F = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q_1q_2}{r^2}$

$= \dfrac{9\times10^9 \times 2\times10^{-7} \times 3\times10^{-7}}{(0.3)^2} = 6 \times 10^{-3}$ N (repulsive)

**5.** Charge is neither created nor destroyed. It is merely transferred from one body to another. Electrons are transferred from glass to silk, so glass has positive charge and silk has negative charge.

**6.** (a) They start from a positive charge and end at a negative charge. They are continuous, because force is continuous. They do not have sudden breaks, otherwise a moving test charge will have to take jumps.

(b) Two lines of force do not intersect each other. If they intersect at a point, there will be two directions of field at that point. Since it is impossible, hence they don't intersect.

**7.** (A) $\dfrac{1}{C} = \dfrac{1}{C_1} + \dfrac{1}{C_2} + \dfrac{1}{C_3} = \dfrac{3}{9\times10^{-12}}$

$\Rightarrow C = 3 \times 10^{-12} = PF$

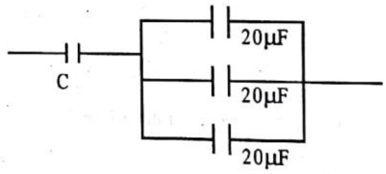
(B) $V = V_1 + V_2 + V_3 = 120 \Rightarrow \dfrac{q}{C_1} + \dfrac{q}{C_2} + \dfrac{q}{C_3} = 120$

$\Rightarrow C_1 = C_2 = C_3 = 9 \times 10^{-12}$

$\dfrac{3q}{9\times10^{-12}} = 120 \Rightarrow q = 360 \times 10^{-12}$ C.

$V = \dfrac{q}{C} = \dfrac{360\times10^{-12}}{9\times10^{-12}} = 40$V.

**8.**




The 3, 20 μF capacitors are in parallel.

$\therefore \quad 20 + 20 + 20 = 60\ \mu F \Rightarrow \dfrac{1}{C} + \dfrac{1}{60} = \dfrac{1}{30}$

$\Rightarrow C = 60\mu F.$

**9.** An equipotential surface is that at every point of which electric potential is same. Consider two points A and B on the equipotential surface.

By definition, potential difference between two points A and B = work done in carrying a unit positive charge from A to B.

$\Rightarrow \quad V_A - V_B = W_{AB} = \vec{E}.d\vec{\ell} \quad$ But $V_A = V_B$

$\therefore \ \vec{E}.d\vec{\ell} = 0$

$\Rightarrow \quad Edl \cos\theta = 0 \Rightarrow \cos\theta = 0 \Rightarrow \theta = 90°$

$\therefore \ \vec{E} \perp d\vec{\ell}$

$\therefore$ Electric field $(\vec{E})$ is directed perpendicular to the equipotential surface.

**10.** On an equipotential surface, no work is done in moving a charge from one point to another. Therefore, the component of electric field intensity along the equipotential surface is zero. So equipotential surfaces are perpendicular to field lines.

**11.** Electric potential at a point is the amount of workdone in moving a unit positive charge from infinity to that point.

Potential energy is the amount of workdone in carrying the total charge from infinity to that point against the electrostatic forces.

**12.** We have Q = CV or $V = \frac{Q}{C}$

$$\Rightarrow \frac{Q}{4\pi\varepsilon_0 r} = \frac{9\times10^9\times1}{10^{-2}} = 9\times10^{11} \text{ Volt.}$$

So, it is not possible for a metallic sphere to hold a charge of 1C because the potential is so high that electric breakdown of air will occur and the entire charge will leak out.

**13.** The relation between dielectric constant and electrical susceptibility of a material is

$K = 1 + \chi$

The electrical susceptibility describes the electrical behaviour of a dielectric. It has different values for different dielectrics. For vacuum $\chi = 0$.

**14.** The torque acting on a dipole placed in a uniform electric field at an angle $\theta$ is $t = \pi E \sin\theta$

(i) When the dipole is parallel to the field, $\overline{P}$ is along $\overline{E}$

$\therefore \theta = 0$

$\therefore t = pE\sin\theta = 0$

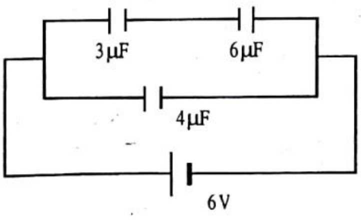
(ii) When the dipole is perpendicular to the field is perpendicular to $\overline{E}$

$\therefore \theta = 90°$

$\therefore$ Torque acting on it is maximum.

$\therefore t_{max} = pE$

**15.**




$$\frac{1}{C_s} = \frac{1}{3} + \frac{1}{6} \Rightarrow C_s = 2\,\mu F \Rightarrow C_p = C_s + C_3 = 2 + 4 = 6\,\mu F$$

$$\text{Energy stored} = \frac{1}{2}CV^2 = \frac{1}{2}\times6\times10^{-6}\times6^2 = 108\times10^{-4}\text{ J.}$$

## LONG ANSWER QUESTIONS :

**1.** (a) *Quantization of electric charge.* It is now a well known fact that all charges occurring in nature are positive or negative integral multiples of a basic unit of electric charge which we take as the magnitude of the charge on an electron. We use symbol *e* for the amount of charge on an electron. Hence charge on an electron is $-e$ and that on a proton happens to be $+e$, while charge on a neutron is zero. Any charged body will have $\pm$ne charge, where *n* is an integer. This fact is called the quantization of electric charge.

(b) At the macroscopic level one deals with charges that are enormous compared to the magnitude of charge *e*. Since $e = 1.6 \times 10^{-19}$ C, a charge of magnitude, say, 1 μC contains something like $10^{13}$ times the electronic charge. At this scale, the fact that charge can increase or decrease only in units of *e* is not very different from saying that charge can take continuous values. Thus, at the macroscopic level, the quantisation of charge has no practical consequence and can be ignored.

**2.** Let $C_1$ and $C_2$ are the capacitances, $q_1$ and $q_2$ are the charges, $V_1$ and $V_2$ are potential of the capacitors respectively.

$\therefore q_1 = C_1V_1$ and $q_2 = C_2V_2$

Before sharing, total charge $= q_1 + q_2 = C_1V_1 + C_2V_2$

When the capacitors are joined by a wire, charge will flow from higher to lower potential till both the potentials are equal. This equal potential is called common potential (V)

If $q'_1$ and $q'_2$ are charges on $C_1$ and $C_2$ after redistribution of charges, then

$$q'_1 = C_1V \text{ and } q'_2 = C_2V$$

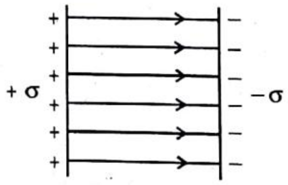
$\because$ Total charge after connecting them together remains same as before.

$$q = q'_1 + q'_2 = C_1V + C_2V = (C_1 + C_2)V$$

$$\therefore (C_1 + C_2)V = C_1V_1 + C_2V_2$$

$$V = \frac{C_1V_1 + C_2V_2}{C_1 + C_2}$$

**3.**




Let A be the plate area of the capacitor.

d is the distance between the plates.

q be the charge on each plate of the capacitor. k is the dielectric constant of the medium between the plates of the capacitor. σ be the surface charge density

$\therefore$ Electric field between the plates $= E = \dfrac{\sigma}{k\varepsilon_0}$; As the potential is same, $V = Ed = \dfrac{\sigma}{k\varepsilon_0} d$

$$\text{Capacitance} = C = \frac{q}{V} = \frac{q}{\dfrac{\sigma d}{k\varepsilon_0}}$$

$$\therefore C = \frac{\sigma A}{\dfrac{\sigma d}{k\varepsilon_0}} = \frac{k\varepsilon_0 A}{d} \qquad [\because q = \sigma A]$$

**4.** Coulomb's law states that, for two charged objects that are much smaller than the distance between them, the force between them varies directly as the product of their charges and inversely as the square of the separation distance and it acts along a straight line from one charge to the other. It can be expressed as where, d is the distance between the charged particles, $q_1$ and $q_2$ represent the charges on the two particles, and k is the proportionality constant. Newton's law of gravitation can be expressed as

$$F = \frac{kq_1q_2}{d^2} \qquad ...(1)$$

where, $F$ is the force of attraction between two objects of masses $m_1$ and $m_2$ separated by a distance $d$.

$$\frac{Gm_1m_2}{d^2} \qquad ....(2)$$

From equations (1) and (2), it seems that Coulomb's law and Newton's law of gravitation are similar in the way that both follow the inverse square law and take the same form. But the two laws are different in the way that Coulombian force can be attractive or repulsive according as the nature of charges but gravitational force between two masses is always attractive in nature.

**5.** According to inverse-square law, the electric force between two charges is inversely proportional to the square of the distance of their separation. Therefore, when the charges are brought to half their original distance of separation, the electric force between them increases by four times.

If the separation distance is made one-quarter their original distance, the force increases by sixteen times.

Similarly, the force between the charges decreases by sixteen times when the separation distance between them is made four times their original distance.

(The inverse square law guides our answer).

## Exercise 2

### MULTIPLE CHOICE QUESTIONS :

**1.** (c) Charges (q) $= 2 \times 10^{-6}$ C, Distance (d)= 3 cm = $3 \times 10^{-2}$ m and electric field (E) $= 2 \times 10^5$ N/C. Torque $(\tau) = q.d.$

$E = (2 \times 10^{-6}) \times (3 \times 10^{-2}) \times (2 \times 10^5)$

$= 12 \times 10^{-3}$ N–m.

**2.** (c) Capacitance of capacitor (C) $= 6\,\mu F = 6 \times 10^{-6}$ F; Initial potential $(V_1) = 10$ V and final potential $(V_2) = 20$ V.

The increase in energy $(\Delta U)$

$$= \frac{1}{2}C\left(V_2^2 - V_1^2\right)$$

$$= \frac{1}{2} \times (6 \times 10^{-6}) \times [(20)^2 - (10)^2]$$

$$= (3 \times 10^{-6}) \times 300 = 9 \times 10^{-4}\ J.$$

**3.** (c) Intensity of electric field due to a Dipole

$$E = \frac{p}{4\pi\varepsilon_0 r^3}\sqrt{3\cos^2\theta + 1} \Rightarrow E \propto \frac{1}{r^3}$$

**4.** (a) At equilibrium, net force is zero

$$\therefore \frac{1}{4\pi\varepsilon_0} \times \frac{Qq}{(r/2)^2} + \frac{1}{4\pi\varepsilon_0} \times \frac{Q^2}{r^2} = 0$$

or $4q = -Q$ or $q = -\dfrac{Q}{4}$.

**5.** (a) Dipole is formed when two equal and unlike charges are placed at a short distance.

6. (d) When oil is placed between space of plates

$$C=\frac{2A\varepsilon_0}{d} \quad ...(1) \quad \left[\because C=\frac{KA\varepsilon_0}{d}, \text{ if } K=2\right]$$

When oil is removed $C'=\frac{A\varepsilon_0}{d}$ ...(2)

On compari both equations, we get $C' = C/2$

7. (a) In air, $F_{air}=\frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r^2}$

In medium, $F_m=\frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{Kr^2}$

$\therefore \frac{F_m}{F_{air}}=\frac{1}{K} \Rightarrow F_m=\frac{F_{air}}{K}$ (decreases K-times)

8. (a) In 1st case when capacitor C attached with battery charged with the energy.

$U_1 = U$ (stored energy on capacitor).

In IInd case after disconnect of battery similar capacitor is attached in parallel with Ist capacitor then $C_{eq}=C'=2C$.

$$\text{Now, } \frac{U_1}{U_2}=\frac{\frac{1}{2}\frac{q^2}{C}}{\frac{1}{2}\frac{q^2}{C'}}=\frac{C'}{C}=\frac{2C}{C} \quad (\because C'=2C)$$

$$U_2=\frac{U}{2}$$

9. (d) According to Gauss's theorem,

electric flux through a closed surface $=\frac{q}{\varepsilon_0}$

where q is charge enclosed by the surface.

10. (b) Energy stored per unit volume

$$=\frac{1}{2}\varepsilon_0E^2=\frac{1}{2}\varepsilon_0\left(\frac{V}{d}\right)^2=\frac{1}{2}\varepsilon_0\frac{V^2}{d^2} \quad \left(\because E=\frac{V}{d}\right)$$

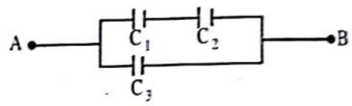
11. (a) Energy stored in capacitor

$$=\frac{1}{2}CV^2=\frac{1}{2}\frac{Q}{V}.V^2 \quad (Q=CV)$$

$$=\frac{1}{2}QV$$

12. (d) For series, $C'=\frac{C_1\times C_2}{C_1+C_2}=\frac{4\times 4}{4+4}=2\mu F$

For parallel, $C_{eq}=C'+C_3=2+4=6\mu F$




13. (b) Charging by induction involves transfer of charges from one part to the other of the body. No loss of charge is involved.

14. (c) Positive charge is due to deficiency of electrons.

15. (c) On charging by conduction, body may gain mass, if it acquires negative charge. It may lose mass, if it acquires positive charge.

16. (d) Coulomb's law is true for all distances small and large. Hence it is called a long range force.

17. (b) $F_m=\frac{F_0}{K}$. For metals $K=\infty$, therefore, $F_m\to 0$, in the thickness of sheet. Hence force between the charges will decrease.

18. (d) Ebonite is the best insulator.

19. (c) A loses electrons and B gains electrons. Therefore, mass of A < mass of B.

20. (b) The radius of soap bubble increases because of outward force acting on the bubble due to charging.

21. (d) $q=\pm ne$ shows that minimum value of $q=\pm 1e$.

where $e=1.6\times 10^{-19}$

Coulomb = Charge of one electron

22. (b) $F_g=\frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r^2}=\frac{F_v}{K}$

As K (for glass) > 1. $\therefore F_g<F_v$

23. (c) The force of $q_1$ or $q_2$ is not affected by $q_3$. However, resultant force on $q_2$ will be affected.

24. (c) Positively charged rod induces negative charge on the side of the sphere closer to the rod and an equal positive charge on the side away from the rod. When the rod is withdrawn, the negative charges move to neutralise the equal positive charge. The charge left is zero.

25. (a) $\frac{F_{e.e}}{F_{p.p}}=10^0=1$, because force depends only on charges, distance and nature of medium.

26. (a) Metal is a good conductor. So, its $K = \infty$.

27. (d)

28. (d) The weight can be increased slightly, if it acquire negative charge & weight can be decreased slightly, if it acquires positive charge.

29. (d) An electric field can deflect only a charged particle.

30. (b) $E = 0$, at any point inside the sphere.

31. (b) E decreases as we move from the surface of the sphere to its centre.

32. (a) A spherical cloud behaves as a solid sphere. Therefore, E decreases directly with the decreasing distance from the centre.

33. (c) For a single negative point charge, electric lines of force are radial and inwards.

34. (d) Electric lines of force are imaginary.

35. (b) Debye is the unit of electric dipole moment.

36. (b) Net force (as well as torque) are experienced by the dipole in a non uniform electric field.

37. (c) In a uniform electric field, net force = 0, but torque $\neq 0$.

38. (d) According to Gauss theorem-the total electric flux

$$\phi = \frac{1}{\varepsilon_o} \times \text{total enclosed charge} = \frac{1}{\varepsilon_o} \times q.$$

Since cube has six faces. Hence electric flux linked with each face $= (1/6\phi) = q/6\varepsilon_o$.

39. (c) We require eight cubes to surround completely this corner charge. So, the flux through one cube is

$$\frac{1}{8} \times \frac{Q}{\varepsilon_o} = \frac{Q}{8\varepsilon_o}$$

40. (a) Positive electric flux is due to + charge. So lines of force are directed outwards.

41. (c) As area of a point is zero,

$\therefore \ \phi = E\,(ds)\cos\theta = E\cos\theta \times 0 = \text{Zero}.$

42. (d) Though electric flux is scalar, yet its value may be positive, negative or zero.

43. (d) At a point on equatorial line of electric dipole, V=0.

## More Than One Correct :

| | | | |
|---|---|---|---|
| 1. | (b, c) | 2. | (a, b, c, d) |
| 3. | (b, c) | 4. | (a, b, c, d) |
| 5. | (b, c, d) | 6. | (b, c,) |
| 7. | (c, d) | 8. | (b, d) |
| 9. | (a, c) | 10. | (a, b, c, d) |
| 11. | (a, c, d) | 12. | (a, c) |
| 13. | (b, c) | 14. | (a, c) |
| 15. | (a, b, d) | 16. | (b, d) |
| 17. | (b, c) | | |

## Fill in the Passage :

| | | |
|---|---|---|
| I. | 1. electrons | 2. friction |
| | 3. transferring | 4. positive charge |
| | 5. Negative charge | |
| II. | 1. $\pm e$ | 2. quantization |
| | 3. multiple | 4. electron |
| | 5. +ne | 6. integral number |
| III. | 1. directly | 2. inversely |
| | 3. $q_1q_2$ | 4. $r^2$ |
| | 5. Permittivity | |

## Passage Based Questions:

Passage I

1. (b) 2. (a) 3. (c)

Passage II

1. (a) 2. (d) 3. (c)

Passage III

1. (b) 2. (a) 3.

## Assertion & Reason :

1. (c) If +ve charge is displaced along x-axis, then net force will always act in a direction opposite to that of displacement and the test charge will always come back to its original position.

2. (d) $q_d = e,\ m_d = 2m_p = 2m$

$q_\alpha = 2e,\ m_\alpha = 4m_p = 4m$

$F_1 = F_\alpha = eE,\ F_2 = F_\alpha = 2eE \neq F_1$

Further, $a_1 = \frac{F_1}{2m} = \frac{eE}{2m}$

and $a_2 = \frac{F_2}{2m} = \frac{2eE}{4m} = \frac{eE}{2m} = a_1$

3. (d) Electric field at any point depends on presence of all charges.

4. (a) No. of lines entering the surface = No. of lines leaving the surface.

5. (d) Charge distribution on each surface makes both capacitor of same potential difference hence charge will not flow.

6. (d) The charge on each of two facing surfaces will be zero.

7. (d) Potential and potential energy are different quantities and cannot be equated.

8. (d) Two equipotential surfaces are not necessarily parallel to each other.

## Multiple Matching Questions :

1. (A) $\rightarrow$ q, s; (B) $\rightarrow$ p, s; (C) $\rightarrow$ p, s; (D) $\rightarrow$ p, r
2. (A) $\rightarrow$ q; (B) $\rightarrow$ q; (C) $\rightarrow$ q; (D) $\rightarrow$ q
3. (A) $\rightarrow$ p; (B) $\rightarrow$ r, s; (C) $\rightarrow$ p; (D) $\rightarrow$ r
4. (A) $\rightarrow$ p, r; (B) $\rightarrow$ q; (C) $\rightarrow$ q, s; (D) $\rightarrow$ q
5. (A) $\rightarrow$ p, s; (B) $\rightarrow$ r, s; (C) $\rightarrow$ p, q; (D) $\rightarrow$ q

## HOTS SUBJECTIVE QUESTIONS :

1. Work done will be same in both the paths as electrostatic force is conservative in nature, so work done doesn't depend on the path followed.

2. $E = \frac{dV}{dr} = \frac{12}{3\times10^{-3}} = 4\times10^{3}$ N/C.

3. Charge on gold nucleus $= q = Ze = 79 \times 1.6 \times 10^{-19}$

$$V = \frac{kq}{r} = \frac{9\times10^{9}\times79\times1.6\times10^{-19}}{6.6\times10^{-15}} = 1.724\times10^{7}\text{ V.}$$

4. $V = \frac{kq}{r} = \frac{9\times10^{9}\times4\times10^{-7}}{0.1} = 3.6\times10^{4}$ V.

5. $E = \frac{kq}{r^2} = 32$ and $V = \frac{kq}{r} = 16$

$$r = \frac{16}{32} = 0.5\text{ m} \therefore \frac{kq}{0.5} = 16 \Rightarrow q = 8.89\times10^{-10}\text{ C}$$

6. $C_1 = \frac{\varepsilon_0 A}{d} = 10$ pF, $C_2 = \frac{k\varepsilon_0 A}{d/2}$

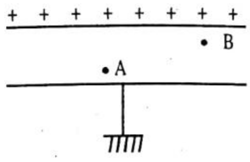
$$= 10\times10\times2\,\mu F = 200\,\mu F.$$

7. $C = \frac{\varepsilon_0 A}{d} = \frac{8.85\times10^{-12}\times6\times10^{-3}}{3\times10^{-3}} = 17.7\,\mu F$

$$q = CV = 17.7\times10^{-12}\times200 = 3.54\times10^{-9}\text{ C.}$$

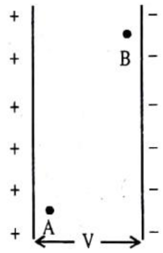
8. For an electric dipole, $F \propto \frac{1}{r^3}$

$\therefore$ New force, $F^1 = \frac{F}{2^3} = \frac{F}{8}$.

9. 


Electric field between the plates of a capacitor is uniform that is constant at every point $\left(E = \frac{\sigma}{\varepsilon_0}\right)$.

$\therefore$ Electric field is same at A and B.

10. 


The field between the two parallel plates is uniform. So, the protons will experience same force.

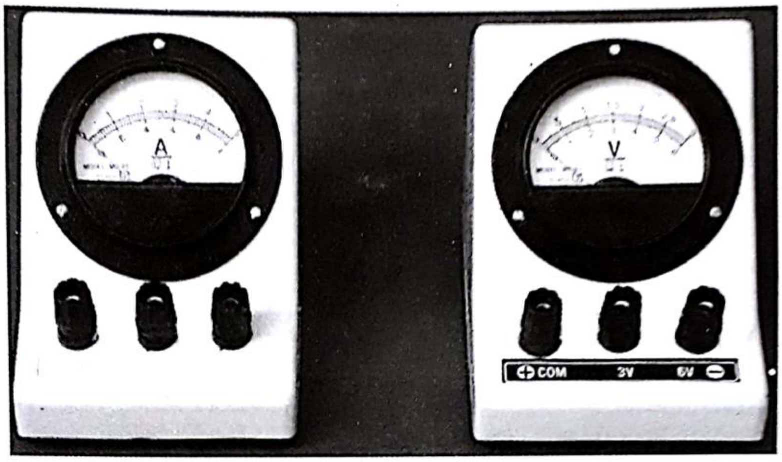
11. Charge will be same, as $Q = CV = 4\pi\varepsilon_0 RV$.
Here, R and V both are same.

12. Energy $= \frac{1}{2}CV^2 = \frac{1}{2}\times470\times10^{-6}\times(20)^2 = 94\times10^{-3}$ J.

13. Force in a medium $= F_m = \frac{F}{k}$

14. It is a scalar quantity.

chapter 4




# CURRENT ELECTRICITY

## Introduction

When we switch on the bulb of our rooms, it glows immediately. When we connect our room heater to the 'pins' placed on the walls, it produces heat. When we provide 'cells' to our torch and press its button, it glows and produces light. All of these phenomena are based on the subject matter of this chapter and the next.

Moving charges produce electric current. Electric current produces many effects like heating effect, chemical effect, magnetic effect, etc. This chapter provides us a strong base on how electric current is produced, which instruments are used for electrical measurement, the factors affecting electric current, etc. The chapter also deals with the factor which resists the flow of electric current known as 'electrical resistance'.

## ELECTRIC CURRENT

We define the electric current, or simply the current, to be the net amount of charges passing per unit time across any section through a conductor. If the charges are positive, the current is assumed to flow in the direction of charges and if the charges are negative, the current is in a direction opposite to the charges.

If $\Delta Q$ is the amount of charge that passes through a particular area in a time interval $\Delta t$, the average current, $I_{av}$, is equal to the ratio of the charge to the time interval.

$$I_{av} = \frac{\Delta Q}{\Delta t}$$

The $SI$ unit of current is ampere ($A$), where $1A = 1\ C/s$

That is, $1A$ of current is equivalent to $1C$ of charge passing through the surface in $1s$. In practice, smaller units of current are often used, such as the milliampere ($1\text{mA} = 10^{-3}A$) and the microampere ($1\mu A = 10^{-6}A$).

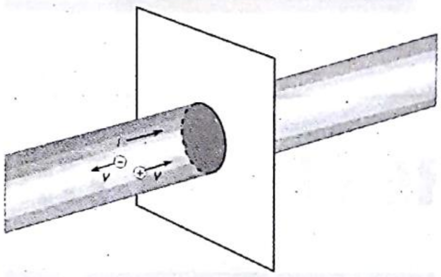


Fig. 4.1

In a conductor such as copper, the current is due to the motion of the negatively charged electrons. Therefore, when we speak of current in an ordinary conductor, such as a copper wire, the direction of the current will be opposite to the direction of flow of electrons.

If the charge on an electron is e and n electrons pass through a point in time t then the total charge passing through that point will be $Q = ne$. Therefore, the current

$$I = \frac{ne}{t} \quad \text{where } e = 1.6 \times 10^{-19} \text{ coulomb.}$$

## CONVENTIONAL FLOW NOTATION

When Benjamin Franklin made his conjecture regarding the direction of charge flow (from the smooth wax to the rough wool), he set a precedent for electrical notation that exists to this day, despite the fact that we know electrons are the constituent units of charge, and that they are displaced from the wool to the wax -- not from the wax to the wool -- when those two substances are rubbed together. This is why electrons are said to have a negative charge: because Franklin assumed electric charge moved in the opposite direction that it actually does, and so objects he called "negative" (representing a deficiency of charge) actually have a surplus of electrons.

By the time the true direction of electron flow was discovered, the nomenclature of "positive" and "negative" had already been so well established in the scientific community that no effort was made to change it, although calling electrons "positive" would make more sense in referring to "excess" charge. You see, the terms "positive" and "negative" are human inventions, and as such have no absolute meaning beyond our own conventions of language and scientific description. Franklin could have just as easily referred to a surplus of charge as "black" and a deficiency as "white," in which case scientists would speak of electrons having a "white" charge (assuming the same incorrect conjecture of charge position between wax and wool).

However, because we tend to associate the word "positive" with "surplus" and "negative" with "deficiency," the standard label for electron charge does seem backward. Because of this, many engineers decided to retain the old concept of electricity with "positive" referring to a surplus of charge, and label charge flow (current) accordingly. This is known as conventional flow notation.

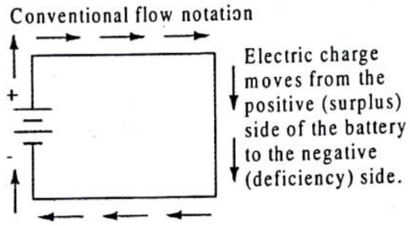



Fig. 4.2 (a)

Others chose to designate charge flow according to the actual motion of electrons in a circuit. This form of symbology is known as electron flow notation:

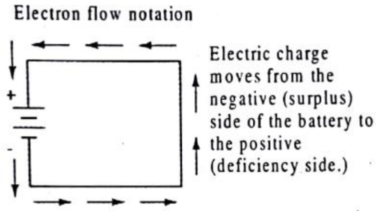



Fig. 4.2 (b)

In conventional flow notation, we show the motion of charge according to the (technically incorrect) labels of + and –. This way the labels make sense, but the direction of charge flow is incorrect. In electron flow notation, we follow the actual motion of electrons in the circuit, but the + and – labels seem backward. Does it matter, really, how we designate charge flow in a circuit? Not really, so long as we're consistent in the use of our symbols. You may follow an imagined direction of current (conventional flow) or the actual (electron flow) with equal success insofar as circuit analysis is concerned.

**Types of Current**

**(a) Direct Current :** The current whose magnitude and direction does not vary with time is called direct current (dc). The various sources are cells, battery, dc dynamo etc.

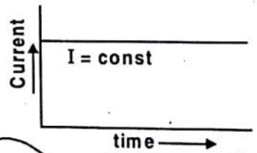



Fig. 4.3 (a)

**(b) Alternating Current :** The current whose magnitude continuously changes with time and periodically changes its direction is called alternating current. It has constant amplitude and has alternate positive and negative halves. It is produced by ac dynamo.

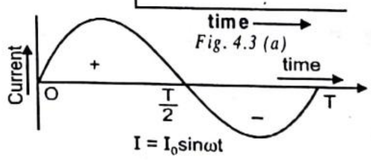



Fig. 4.3 (b)

*When an electric light switch is made on, the light comes on immediately. An electric signal in a conductor travels at a speed of about $3 \times 10^8$ m/s.*

*The current may be constituted by motion of different type of charge carriers in different situations.*

| S.No. | Nature of material | Cause of current |
|---|---|---|
| 1. | Conductors | Motion of electrons |
| 2. | Vacuum tubes | Motion of electrons |
| 3. | Semiconductors | Motion of holes and electrons |
| 4. | Electrolytes | Motion of positive and negative ions |
| 5. | Discharge tube | Motion of positive and negative ions |

## CHECK Point

- **If a current of one-or two-tenths of an ampere were to flow into one of your hands and out the other, you would probably be electrocuted. But, if the same current were to flow into your hand and out the elbow above the same hand, you could survive, even though the current might be large enough to burn your flesh. Explain.**

**SOLUTION**

If a current of one-or-two-tenths of an ampere flows into one of our hands and out the other, we may be electrocuted, probably, because the electric circuit formed becomes closed. But when the same current flows into the hand and out the elbow above the same hand, the electric circuit is not completed, and we could survive.

### ILLUSTRATION 4.1

If a current 3.2 ampere per second flows through a conducting wire, calculate the number of electrons passing through the wire.

**SOLUTION :**

Here, $I = 3.2A$, $t = 1$ second, $n = ?$, $e = 1.6 \times 10^{-19}$ coulomb

$$I = \frac{ne}{t};\ 3.2 = \frac{n \times 1.6 \times 10^{-19}}{1}$$

or $n \times 1.6 \times 10^{-19} = 3.2$ or $n = \frac{3.2}{1.6 \times 10^{-19}}$ $\therefore\ n = 2 \times 10^{19}$ electrons

### ILLUSTRATION 4.2

If 25 coulomb charge flow in a conductor in 5 seconds then find out the value of electric current in it.

**SOLUTION :**

Electric current $I = \frac{Q}{t}$ $[Q = 25 \text{ coulomb}, t = 5 \text{ second}, I = ?]$

$$I = \frac{25}{5} = 5 \text{ ampere}$$

### ILLUSTRATION 4.3

If a light bulb uses 0.50 ampere of current, how much charge flows through it in 5 minutes ?

**SOLUTION :**

Five minute is 300 seconds, so from

$$\Delta q = I\Delta t$$

$$\Delta q = (0.50A)\,(300s) = 150C$$

## RESISTANCE

Directly connecting the poles of a voltage source together with a single piece of wire is dangerous because the magnitude of electric current may be very large in such a short circuit, and the release of energy very dramatic (usually in the form of heat),you may have heard about firing due to short circuit. Usually, electric circuits are constructed in such a way as to make practical use of that released energy, in as safe a manner as possible. One practical and popular use of electric current is for the operation of electric lighting. The simplest form of electric lamp is a tiny metal "filament" inside of a clear glass bulb, which glows white-hot (incandesces) with heat energy when sufficient electric current passes through it. Like the battery, it has two conductive connection points, one for electrons to enter and the other for electrons to exit. Connected to a source of voltage, an electric lamp circuit looks something like this:

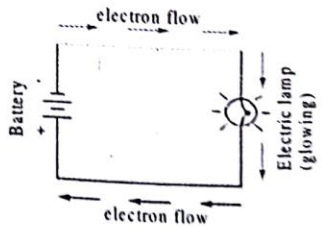



Fig. 4.4

As the electrons work their way through the thin metal filament of the lamp, they encounter more opposition to motion than they typically would in a thick piece of wire. This opposition to electric current depends on the type of material, its cross-sectional area, and its temperature. It is technically known as resistance. (It can be said that conductors have low resistance and insulators have very high resistance.) This resistance serves to limit the amount of current through the circuit with a given amount of voltage supplied by the battery, as compared with the "short circuit" where we had nothing but a wire joining one end of the voltage source (battery) to the other.

When electrons move against the opposition of resistance, due to friction heat is generated. Just like mechanical friction, the friction produced by electrons flowing against a resistance manifests itself in the form of heat. The concentrated resistance of a lamp's filament results in a relatively large amount of heat energy dissipated at that filament. This heat energy is enough to cause the filament to glow white-hot, producing light, whereas the wires connecting the lamp to the battery (which have much lower resistance) hardly even get warm while conducting the same amount of current. How to deal with resistance mathematically? You will find the answer in Ohm's law section.

## Knowledge ENHANCER

The reciprocal of resistance is called conductance G = 1/R

Its SI unit is ohm$^{-1}$ or mho or siemen (s).

The substances which obey Ohm's law are called Ohmic or linear conductors. The resistance of such conductors is independent of magnitude and polarity of applied potential difference. Here the graph between $I$ and $V$ is a straight line passing through the origin. The reciprocal of slope of straight line gives resistance

$$R = \frac{V}{I} = \frac{1}{\tan\theta} = \text{constant.}$$

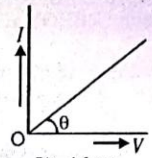



*Fig. 4.5 (a)*

Examples silver, copper, mercury, carbon, mica etc.

The substances which do not obey Ohm's law are called non-ohmic or non linear conductors. The $I-V$ curve is not a straight line.

i.e. *p-n* diode, transistors, thermionic valves, rectifiers etc.

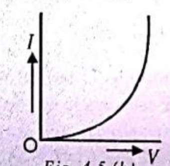



*Fig. 4.5 (b)*

## FACTORS AFFECTING RESISTANCE

The resistance of a conductor depends on *temperature*, *nature* of *material*, *length* and *area* of *cross-section*.

If the resistance of the wire at 0°C be $R_0$ and at t°C be $R_t$, then the value of $R_t$ is obtained by the following formula

$$R_t = R_0(1+\alpha t) \quad \text{..........(1)}$$

where $\alpha$ is a constant which is called the 'temperature coefficient of resistance' of the material of the wire.

From eq. (1), we have $\alpha = \dfrac{R_t - R_0}{R_0 \times t}$ per °C

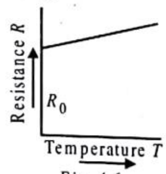



*Fig. 4.6*

If $R_0 = 1$ ohm, $t = 1$°C then $\alpha = (R_t - R_0)$ = increase in resistance.

Therefore, if the resistance of a wire at 0°C be 1 ohm, then on raising its temperature to 1°C, the increase in its resistance will be equal to the "temperature coefficient of resistance' of the material of that wire. For most of the metals, the value of $\alpha$ is nearly (1/273) per °C. Hence, by eq. (1), we have

$$R_t = R_0\left(1+\frac{t}{273}\right) = R_0\frac{(273+t)}{273} = R_0\left(\frac{T}{273}\right)$$

where $T$ is the absolute temperature. Thus, $R_t \propto T$

Thus, the resistance of a pure metallic wire or the resistivity of a metal is directly proportional to its absolute temperature.

The resistivity of alloys also increases with rise in temperature, but this increase is much smaller compared to pure metals.

There are certain alloys such as manganin, constantan, nichrome, etc., whose resistivity is little affected by temperature, that is, their temperature coefficient of resistance is negligible. On account of their high resistivity and negligible temperature coefficient of resistance, these alloys are used to make wires for standard resistances, resistance boxes, etc.

## COLOUR CODE FOR CARBON RESISTORS

**First Colour Code**

| Colour | Strip A | Strip B | Strip C | Strip D Tolerance |
|---|---|---|---|---|
| Black | 0 | 0 | $10^0$ | |
| Brown | 1 | 1 | $10^1$ | |
| Red | 2 | 2 | $10^2$ | |
| Orange | 3 | 3 | $10^3$ | |
| Yellow | 4 | 4 | $10^4$ | |
| Green | 5 | 5 | $10^5$ | |
| Blue | 6 | 6 | $10^6$ | |
| Violet | 7 | 7 | $10^7$ | |
| Grey | 8 | 8 | $10^8$ | |
| White | 9 | 9 | $10^9$ | |
| Gold | – | – | $10^{-1}$ | ±5% |
| Silver | – | – | $10^{-2}$ | ±10% |
| No Colour | – | – | – | ±20% |

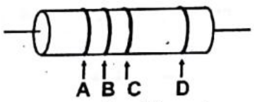


*Fig. 4.7*

**Aid to memory :** BBROY of Great Britain has a Very Good Wife.

The first two rings give first two significant figures of resistance. The third ring indicates the decimal multiplier i.e. the number of zeros that will follow the two significant figures. The fourth ring shows tolerance or percentage accuracy.

**Factors on which the resistance of a conductor depends**

The resistance of ohmic circuit elements such as metal wires or carbon resistor depends on their geometries.

To find dependence, first we will keep the thickness of the object (like a copper wire) fixed and just increase or decrease the length of the wire. If we apply a potential difference across the ends of the wire and use current and potential difference measurements, we can determine its resistance as a function of length. We find that there is a proportionality between the length $L$ of the wire and the resistance of the wire $R$. Thus we can write

$$R = kL$$

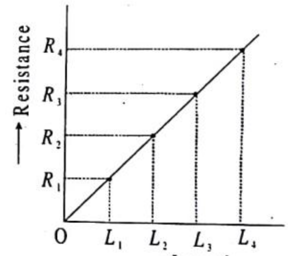


*Fig. 4.8 (a)*

If instead we fix the length of the copper wire and vary the thickness or cross-sectional area A then we find the resistance of the copper decreases as the cross-sectional area A of the wire increases. In fact we get an inverse relationship so that $R = k'\dfrac{1}{A}$

Combining these two expressions gives us : $R = kk'\dfrac{L}{A}$

To simplify this expression, we can replace the product of the two constants with a single new constant and write $R = \rho\dfrac{L}{A}$

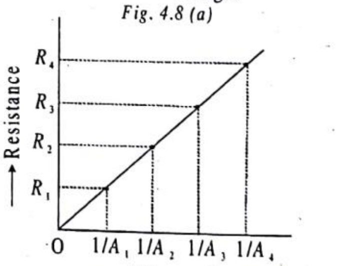


*Fig. 4.8 (b)*

Where ρ is a constant, which is called the specific resistance or resistivity of the conducting material. It does not depend on the area of cross-section. Resistivity depends only on the nature of material and temperature.

$$\rho = R\frac{L}{A} \quad \therefore \text{ unit of } \rho = \frac{\text{ohm} \times \text{m}^2}{\text{m}} = \text{ohm} \times \text{meter}$$

**Definition of resistivity :** If $L = 1$ meter, $A = 1$ square meter then $\rho = R$ (numerically) i.e. resistance of a wire of unit length and unit area of cross section is numerically equal to the resistivity or specific resistance of the material of wire. Remember resistance is a property of an object. Resistivity is a property of a material.

Resistance of some metallic conductors rises with increase in temperature, e.g. copper, silver etc. Resistance of some alloys such as manganin and constantan changes very slowly with increase in temperature. Contrary to this, resistance of semiconductors such as germanium (Ge), silicon (Si) etc. decreases with increase in temperature.

On decreasing temperature of some metals, the resistance becomes zero at a certain temperature.

**For example :** Resistance of mercury becomes zero at 4.2 K temperature.

**Activity :**

Complete an electric circuit consisting of a cell, an ammeter, a nichrome wire of length $l$ [say, marked (1)] and a plug key, as shown in Fig. 4.9

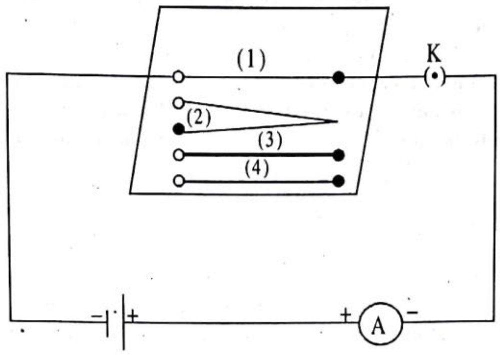



*Fig. 4.9 : Electric circuit to study the factors on which the resistance of conducting wires depends.*

Now, plug the key. Note the current in the ammeter.

Replace the nichrome wire by another nichrome wire of same thickness but twice the length, that is $2l$ [marked (2) in the Fig]. Note the ammeter reading.

Now replace the wire by a thicker nichrome wire, of the same length $l$ [marked (3)]. A thicker wire has a larger cross-sectional area. Again note down the current through the circuit.

Instead of taking a nichrome wire, connect a copper wire [marked (4) in Fig. ] in the circuit. Let the wire be of the same length and same area of cross-section as that of the first nichrome wire [marked (1)]. Note the value of the current.

Notice the difference in the current in all cases.

Does the current depend on the length of the conductor?

Does the current depend on the area of cross-section of the wire used?

## Knowledge ENHANCER

If a wire is stretched such that length becomes n times, resistance becomes $n^2$ times. Due to stretching, the cross-sectional area decreases to $n$ times and volume (or mass) remains constant.

Volume $(V) = A\ell$,

$A\ell = A'n\ell$

New cross-sectional arqea $A' = \dfrac{A}{n}$

New resistance $R' = \dfrac{\rho n\ell}{A/n} = \dfrac{n^2\rho\ell}{A} = n^2 R$

The fractional change in resistance without change in volume or mass are :

(a) When change in length is small ($\leq 5\%$) fractional change in $R$ is $\dfrac{\Delta R}{R} = \dfrac{2\Delta L}{L}$

(b) When change in radius is small ($\leq 5\%$) fractional change in $R$ is $\dfrac{\Delta R}{R} = \dfrac{-4\Delta r}{r}$

(c) When change in area is small ($\leq 5\%$) fractional change in $R$ is $\dfrac{\Delta R}{R} = \dfrac{-2\Delta A}{A}$

## CHECK Point

- Choose the correct alternative

(a) **Alloys of metals usually have (greater/less) resistivity than that of their constituent metals.**

(b) **Alloys usually have much (lower/higher) temperature coefficients of resistance than puremetals.**

(c) **The resistance of graphite and most non-metals increases/decreases with increase in temperature.**

(d) **The resistivity of a semiconductor increases/decreases rapidly with increasing temperature.**

(e) **The resistivity of the alloy manganin is nearly independent of/increases rapidly with increases of temperature.**

(f) **The resistivity of a typical insulator (e.g., amber) is greater than that of a metal by a factor of the order of ($10^{22}/10^{23}$).**

### SOLUTION

(a) Alloys of metals usually have *greater* resistivity than that of their constituent metals.

(b) Alloys usually have much *lower* temperature coefficients of resistance than pure metals.

(c) The resistance of graphite and most non metals *decreases* with increase in temperature.

(d) The resistivity of a semiconductor *decreases* rapidly with increasing temperature.

(e) The resistivity of the alloy manganin is *nearly independent* of increasing temperature.

(f) The resistivity of a typical insulator (e.g. amber) is greater than that of a metal by factor of the order of $10^{22}$.

## ILLUSTRATION 4.4

The resistivity of copper at room temperature is $1.72 \times 10^{-6}$ ohm-centimeter. What is the resistance of a copper wire 35 meters long and 0.025 centimeter in cross section.

**SOLUTION :**

$$R = \frac{\rho \ell}{A} = \frac{(1.72\times10^{-6}\,\Omega\text{ cm})\,(3500\text{ cm})}{0.025\text{ cm}^2} = 0.24\,\Omega$$

## ILLUSTRATION 4.5

The resistance of a wire of length 100 cm and of uniform area of cross-section 0.020 cm$^2$, is found to be 2.0 ohm. Calculate sp. resistance of wire

**SOLUTION :**

$\ell = 100$ cm, $A = 0.020\text{ cm}^2$, $R = 2.0\,\Omega$

$$\text{Sp. resistance } \rho = \frac{RA}{\ell} = \frac{2.0\times0.020}{100} = 0.0004\,\Omega-\text{cm}$$

## ILLUSTRATION 4.6

What length of resistance wire of resistivity $100 \times 10^{-8}\,\Omega$m, area of cross-section $2.5 \times 10^{-7}$ m$^2$, would be needed to make a resistor of $57.6\Omega$.

**SOLUTION :**

$R = 57.6\Omega$, $A = 2.5 \times 10^{-7}\, m^2$, $l = ?$

$$\rho = 100\times10^{-8}\,\Omega\text{m}, \quad R = \frac{\rho l}{A} \quad \text{so,} \quad l = \frac{RA}{\rho} \Rightarrow l = \frac{57.6\times2.5\times10^{-7}}{100\times10^{-8}}\frac{\text{m}^2}{\text{m}} = 1.44\text{ m}$$

## ILLUSTRATION 4.7

Two wires $A$ and $B$ of equal masses and of same metal are taken. The diameter of the wire $A$ is half the diameter of the wire $B$. If the resistance of the wire $A$ be 24 ohm, calculate the resistance of the wire $B$.

**SOLUTION :**

Let $r_A$ be the radius and $\ell_A$ the length of the wire $A$, and $r_B$ the radius and $\ell_B$ the length of the wire $B$ > Both the wires are of the same material (density $d$). Since the masses of the two wires are equal, we have

$$\pi r_A^2 \ell_A \times d = \pi r_B^2 \ell_B \times d$$

$$\therefore \quad \frac{\ell_A}{\ell_B} = \frac{r_B^2}{r_A^2} \quad \text{..........(1)}$$

Resistance of the wire $A$ is $R_A = \rho \dfrac{\ell_A}{\pi r_A^2}$, Resistance of the wire $B$ is $R_B = \rho \dfrac{\ell_B}{\pi r_B^2}$

where $\rho$ is the specific resistance of the material of the wires

$$\therefore \quad \frac{R_A}{R_B} = \frac{\ell_A}{\ell_B} \times \frac{r_B^2}{r_A^2} = \frac{r_B^4}{r_A^4}$$

But $r_A = \dfrac{1}{2} r_B$ (given) $\therefore \quad \dfrac{R_A}{R_B} = 16 \quad$ or $\quad R_B = \dfrac{1}{16} R_A = \dfrac{1}{16} \times 24$ ohm $= 1.5$ ohm

**ILLUSTRATION 4.8**

Calculate the resistance of 1 km long copper wire of radius 1 mm. (Resistivity of copper is $1.72 \times 10^{-8}\ \Omega$m)

**SOLUTION :**

Given $\ell = 1$ km $= 1000$m, $r = 1$ mm $= 10^{-3}$ m, $A = \pi r^2 = 3.14 \times (10^{-3})^2 = 3.14 \times 10^{-6}$ m$^2$

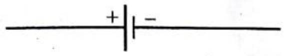
Resistivity $\rho = 1.72 \times 10^{-8}\ \Omega$m

$$R = \rho \frac{l}{A} = \frac{1.72 \times 10^{-8} \times 1000}{3.14 \times 10^{-6}} \quad \text{or} \quad R = 5.5\ \Omega.$$

## ELECTRIC CIRCUIT

To learn more on electricity we need to draw electric circuits with elements like batteries (combination of cells), bulbs, wire, switches, ammeter, voltmeter, Rheostat etc.

1. **Cell :** Direct current source of electromotive force.



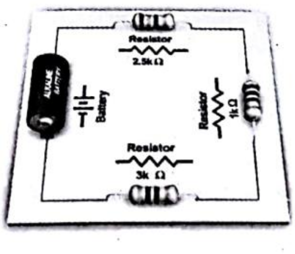
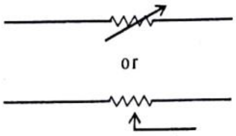




*Fig. 4.10 : Simple circuit showing battery and resistor.*

2. **Rheostat (variable resistance) :** Wire of special type of alloy like manganin, eureka, nichrome etc. is wound on a hollow cylinder of china clay. It controls the current in the electric circuit.

(a)




(b)

*Fig. 4.11*

3. **Switch :** It is used to close or open the electric circuit, controls the movement of electrons in a circuit.

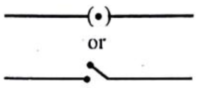



*Fig. 4.12*

4. **Ammeter :** Determines the value of current flowing in the circuit. The resistance of ammeter is small and it is used in series with the circuit.

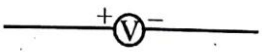
(a)


(b)

*Fig. 4.13*

5. **Voltmeter :** Determines the potential difference between two points in the circuit. Its resistance is high and it is used in parallel with the resistance wire.


(a)




(b)

*Fig. 4.14*

**CHECK Point**

- **One example of a water system is a garden hose that waters a garden. Another is the cooling system of an automobile. Which of these exhibits behavior more analogous to that of an electric circuit? Why?**

**SOLUTION**

The garden hose is more analogous to an electric circuit as it contains a source of water in which there is a pressure difference like an electric circuit contains a source of electrical energy which has a potential difference. Also, the water is supplied through a pipe in the same way as a conducting path is provided for the flow of electrical energy in a circuit.

## OHM's LAW

According to Ohm's law "The current passing through a conductor is directly proportional to the potential difference between its ends, provided the physical conditions of conductor remain unchanged."

$V \propto I$ or $V = RI$

where $R$ is a constant which is called resistance.

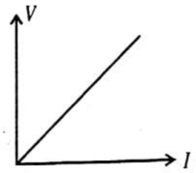



Fig. 4.15

**Unit of resistance**

$$R = \frac{V}{I} = \frac{\text{volt}}{\text{ampere}} = \text{ohm } (\Omega)$$

The unit of resistance is ohm (Ω).

If $I = 1$ ampere, $V = 1$ volt then $R = 1\Omega$.

The resistance of a conductor is 1 ohm if a potential difference of 1 volt is produced across its ends when 1 ampere of the current flows through it.

The conductors, which obey the Ohm's law are called the ohmic conductors or linear resistances. All metallic conductors (such as silver, aluminium, copper, iron, etc.) are the ohmic conductors.

The conductors, which do not obey the Ohm's law are called the non-ohmic conductors or non-linear resistances. Examples are, diode valve, triode valve, transistors, electrolyte, etc.

*It is sometime contended that $R = \Delta V/i$ (or $\Delta V = iR$) is a statement of Ohm's law. That is not true! This equation is the defining equation for resistance, and it applies to all conducting devices, whether they obey Ohm's law or not. If we measure the potential difference $\Delta V$ across and the current $i$ through the device, even a bulb or other non-ohmic device, we can find its resistance at that value of $\Delta V$ as $R = \Delta V/i$. The essence of Ohm's law, however, is a plot of $i$ versus $\Delta V$ that it is straight line, so that the value of $R$ is independent of the value of $\Delta V$.*

**Activity :**

- Take a nichrome wire, a torch bulb, a 10 W bulb and an ammeter (0 – 5 A range), a plug key and some connecting wires.
- Set up the circuit by connecting four dry cells of 1.5 V each in series with the ammeter leaving a gap $XY$ in the circuit, as shown in Figure

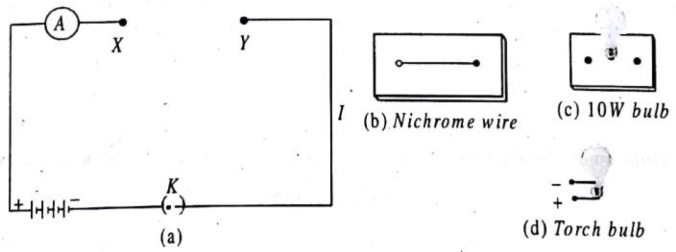



Fig. 4.16

- Complete the circuit by connecting the nichrome wire in the gap XY. Plug the key. Note down the ammeter reading. Take out the key from the plug. Always take out the key from the plug after measuring the current through the circuit.
- Replace the nichrome wire with the torch bulb in the circuit and find the current through it by measuring the reading of the ammeter.
- Now repeat the above step with the 10 W bulb in the gap $XY$.
- Are the ammeter readings differ for different components connected in the gap $XY$? What do the above observations indicate?
- You may repeat this Activity by keeping any material component in the gap. Observe the ammeter readings in each case. Analyse the observations.

## VERIFICATION OF OHM's LAW

Set up a circuit as shown in figure with a battery switch ($S$), a rheostat ($Rh$), ammeter ($a$), a resistor ($R$) and a voltmeter ($V$). Close the circuit and adjust the rheostat such that the ammeter and the voltmeter show a measurable reading $I$ and $V$ respectively. Repeat the experiment for different values of $I$ and $V$ by adjusting the rheostat.

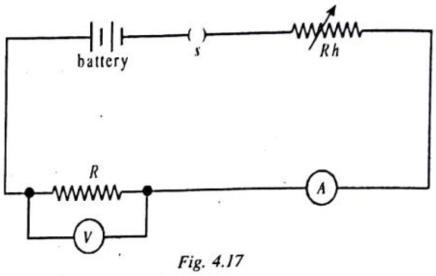



*Fig. 4.17*

Tabulate your results as shown below :

| Trial No. | Potential difference $V$ (volt) | Current I (ampere) | $\frac{V}{I} = r$ (ohm) |
|---|---|---|---|
| 1.<br>2.<br>3. | | | |

Plot a graph of $V$ against $I$. If it is a straight line passing Fig. 4.18 through the origin we can conclude that P.D. '$V$' is directly proportional to the current '$I$' and Ohm's law is verified.

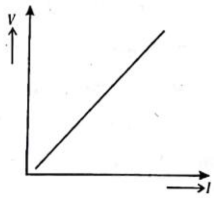



*Fig. 4.18*

**Limitation of Ohm's Law**

1. Ohm's law does not apply to conductors such as diode, radio valves, metal rectifiers, electricity through gases.
2. Ohm's law is applicable only when the physical conditions remain constant, for example the resistance of some conductors will vary if the wires are heated or placed under tension.
3. Ohm's law is applicable only when the temperature of the conductor is constant. Generally the resistance of pure metals increases with temperature but the resistance of certain other conducting materials like carbon decreases with temperature. There are certain metal alloys of magnesium and copper whose resistance changes with temperature.

### CHECK Point

- **Is Ohm's law universally applicable for all conducting elements? If not, give examples of elements which do not obey Ohm's law.**

**SOLUTION**

Ohm's law is not a fundamental law in nature. It is not universally followed semiconductor diodes, Transistor, Thermistors, vacuum tubes do not follow ohm's law.

### ILLUSTRATION 4.9

Calculate the potential difference required across a conductor of resistance 5Ω to flow a current of 1.5 A through it.

**SOLUTION :**

Given $R = 5\Omega$, $I = 1.5\,A$, $V = ?$

From Ohm's, law, $V = IR = 1.5 \times 5 = 7.5\ V$

**ILLUSTRATION—4.10**

How much electric current is produced on applying potential difference of 30 volts on a wire of resistance 20 ohm ?

**SOLUTION :**

$$I = \frac{V}{R} = \frac{30}{20} = 1.5 \text{ ampere}$$

**ILLUSTRATION—4.11**

If ampere current flowing through a resistance wire develops a potential difference of 50 volts across its ends, find the resistance of the resistance wire.

**SOLUTION :**

$$R = \frac{V}{I} = \frac{50}{5} = 10 \text{ ohm}$$

**ILLUSTRATION—4.12**

The potential difference between the terminals of an electric heater is 60 $V$ when it draws a current of $4A$ from the source. What current will the heater draw if the potential difference is increased to 120 $V$ ?

**SOLUTION :**

We are given, potential difference $V = 60\ V$, current $I = 4A$.

According to Ohm's law, $R = \frac{V}{I} = \frac{60V}{4A} = 15\ \Omega$

When the potential difference is increased to 120V the current is given by

$$\text{current} = \frac{\text{V}}{\text{R}} = \frac{120\text{V}}{15\Omega} = 8\text{A}$$

The current through the heater becomes 8A.

**ILLUSTRATION—4.13**

A relay with a resistance of 12 ohms is in an electric circuit with one side at a potential of 85 volts and the other at 71 volts. How much current is in the relay ?

**SOLUTION :**

The potential difference across the relay is $(85V - 71V) = 14V$.

$$I = \frac{\Delta V}{R} = \frac{14V}{12\Omega} = 1.2\ A$$

## COMBINATION OF RESISTORS

In many practical applications to have desired value of resistance two or more resistances are required to be combined. This can be done in two ways : (i) **In series** and (ii) **In parallel**. Sometimes resistances are to be combined in such a way that some resistances be in series and some in parallel. Such a combination is called mixed grouping.

If, in an electrical circuit, two or more resistances connected between two points are replaced by a single resistance such that there is no change in the current of the circuit and in the potential difference between those two points, then the single resistance is called the 'equivalent resistance'.

When the resistance of a circuit is to be increased, they are combined in series and when heavy current is to be passed, they are combined in parallel so as to decrease the total resistance.

## SERIES COMBINATION

In this combination, the resistances are joined end to end. Thus the second end of each resistance is joined to the first end of the next resistance, and so on. The first end of the first resistance and the second end of the last resistance are connected to the cell. In this combination, the same current flows in all the resistances but the potential differences between their ends are different according to their resistances.

In figure, three resistances AB, BC and CD are connected in series. Suppose their resistances are $R_1$, $R_2$ and $R_3$ respectively. Let the 'equivalent resistance' of these resistances be $R$.

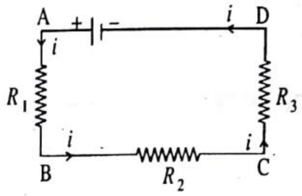



*Fig. 4.19*

Suppose a current is flowing in all the three resistances. Suppose the potential differences between the ends of the resistances $R_1$, $R_2$ and $R_3$ are $V_1$, $V_2$ and $V_3$ respectively. Then, according to Ohm's law we have

$$V_1 = iR_1,\quad V_2 = iR_2 \quad \text{and} \quad V_3 = iR_3.$$

If the potential difference between points $A$ and $D$ be $V$, then

$$V = V_1 + V_2 + V_3 = iR_1 + iR_2 + iR_3 = i\,(R_1 + R_2 + R_3) \qquad \text{.......... (1)}$$

The equivalent resistance between points $A$ and $D$ is $R$. Therefore

$$V = iR \qquad \text{.......... (2)}$$

Comparing eq. (1) and (2), we get $\quad iR = i\,(R_1 + R_2 + R_3)$

$$R = R_1 + R_2 + R_3$$

That is, the equivalent resistance of the resistances connected in series is equal to the sum of those resistances and is thus greater than any individual resistance.

**Activity:**

- Join three resistors of different values in series. Connect them with a battery, an ammeter and a plug key, as shown in Fig. You may use the resistors of values like 1Ω, 2Ω, 3Ω etc., and a battery of 6*V* for performing this Activity.
- Plug the key. Note the ammeter reading.
- Change the position of ammeter to anywhere in between the resistors. Note the ammeter reading each time.
- Do you find any change in the value of current through the ammeter ?

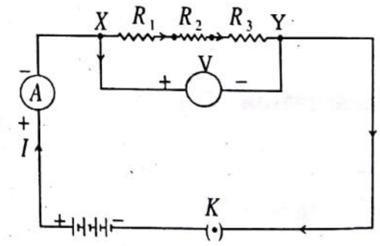



*Fig. 4.20*

**Activity:**

- In previous Activity, insert a voltmeter across the ends $X$ and $Y$ of the series combination of three resistors, as shown in figure.
- Plug the key in the circuit and note the voltmeter reading. It gives the potential difference across the series combination of resistors. Let it be $V$. Now, measure the potential difference across the two terminals of the battery. Compare the two values.
- Take out the plug key and disconnect the voltmeter. Now, insert the voltmeter across the ends $X$ and $P$ of the first resistor, as shown in Figure.
- Plug the key and measure the potential difference across the first resistor. Let it be $V_1$.

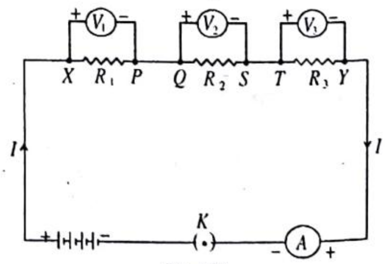



*Fig. 4.21*

- Similarly, measure the potential difference across the other two resistors, separately. Let these values be $V_2$ and $V_3$, respectively.
- Deduce a relationship between $V$, $V_1$, $V_2$ and $V_3$.

## PARALLEL COMBINATION

When two or more resistances are combined in such a way that their first ends are connected to one point and the second ends to another point then this combination is in parallel. In this combination, the potential difference between the ends of all the resistances is same but the current in different resistances are different.

In Fig. 4.22, three resistances $R_1$, $R_2$ and $R_3$ are joined in parallel between the points $A$ and $B$. Suppose the current flowing from the cell is $i$. At the point $A$, this current is divided into three parts. Suppose $i_1$, $i_2$ and $i_3$ are the currents in $R_1$, $R_2$ and $R_3$ respectively. At the point $B$, these three currents meet and form the main current $i$. Thus, we have

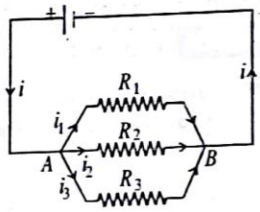



Fig. 4.22

$$i = i_1 + i_2 + i_3 \qquad \text{.............(1)}$$

Let the potential difference between the points $A$ and $B$ be $V$. Since each resistance is connected between $A$ and $B$, the potential difference between the ends of each will be $V$. Therefore,

$$i_1 = \frac{V}{R_1}, \quad i_2 = \frac{V}{R_2} \text{ and } i_3 = \frac{V}{R_3}$$

Substituting these values in eq. (1) we get,

$$i = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \qquad \text{.............(2)}$$

If the equivalent resistance between the points $A$ and $B$ be $R$, then

$$i = V/R \qquad \text{.............(3)}$$

Comparing eq. (2) and (3), we get

$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \quad \text{or} \quad \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

That is, the reciprocal of the equivalent resistance of the resistances connected in parallel is equal to the sum of the reciprocals of those resistances.

In parallel combination, the equivalent resistance $R$ is less than even the smallest resistance connected. For example, if we connect two resistors of resistance $1\Omega$ and $100\ \Omega$ in parallel, the equivalent resistance R will be less than $1\Omega$ as shown below :

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{2} + \frac{1}{100} = \frac{101}{100} \quad \text{or} \quad R = \frac{100}{101} = 0.99\ \Omega$$

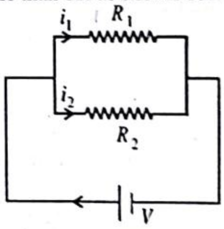



Fig. 4.23

If resistance $R_1$ and $R_2$ are connected in parallel and $i$ is the total current drawn from cell then

$$i = i_1 + i_2 \qquad \text{..........(1)}$$

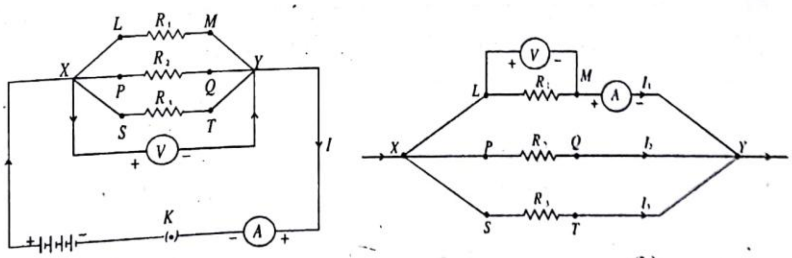
$$V = i_1 R_1 = i_2 R_2 \qquad \text{..........(2)}$$

Solving eq. (1) and (2)

$$i_2 = \frac{iR_1}{R_1 + R_2} \quad \text{and} \quad i_2 = \frac{iR_1}{R_1 + R_2}$$

**Activity :**

Make a parallel combination, $XY$, of three resistors having resistances $R_1$, $R_2$, and $R_3$, respectively. Connect it with a battery, a plug key and an ammeter, as shown in Fig 4.24 (a). Also connect a voltmeter in parallel with the combination of resistors. Plug the key and note the ammeter reading. Let the current be $I$. Also take the voltmeter reading. It gives the potential difference $V$, across the combination. The potential difference across each resistor is also $V$. This can be checked by connecting the voltmeter across each individual resistor [Fig. 4.24(b)].




(a) (b)

Fig. 4.24

Take out the plug from the key. Remove the ammeter and voltmeter from the circuit. Insert the ammeter in series with the resistor $R_1$, as shown in Fig. 4.24 (b). Note the ammeter reading, $I_1$.
Similarly, measure the currents through $R_2$ and $R_3$. Let these be $I_2$ and $I_3$, respectively. What is the relationship between $I$, $I_1$, $I_2$ and $I_3$?

## CHECK Point

- **Given $n$ resistors each of resistance $R$, how will you combine them to get the (i) maximum (ii) minimum effective resistance? What is the ratio of the maximum to minimum resistance?**

**SOLUTION**

(i) For maximum effective resistance, all the resistors should be joined in series.

$R_{max} = R+R+R+........n$ or $R_{max} = nR$

(ii) For minimum effective resistance all the resistors should be joined in parallel

$$\frac{1}{R_{min}} = \frac{1}{R}+\frac{1}{R}+\frac{1}{R}+........n \text{ or } \frac{1}{R_{min}} = \frac{n}{R}$$

So $R_{min} = \dfrac{R}{n}$

Now, $\dfrac{R_{max}}{R_{min}} = n^2$

## ILLUSTRATION 4.14

Three resistances of 2, 3 and 5 ohms are connected in series. If the combination is connected to a battery of 4 volt then what will be (i) current in each resistance (ii) potential difference across each resistance ?

**SOLUTION :**

Total resistance in series

$$R = R_1 + R_2 + R_3$$
$$R = 2+3+5 = 10\,\Omega.$$

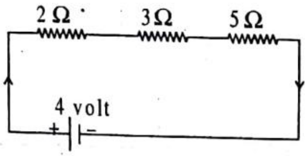



Fig. 4.25

(i) Current flowing through each resistance will be same

$$I = \frac{V}{R} = \frac{4}{10} = 0.4 \text{ ampere}$$

(ii) Potential difference across each resistance will be determined by formula $V = IR$.

Potential difference across 2Ω resistance $V_1 = IR_1 = 0.4 \times 2 = 0.8$ volt

Potential difference across 3Ω resistance $V_2 = IR_2 = 0.4 \times 3 = 1.2$ volt

Potential difference across 5Ω resistance $V_3 = IR_3 = 0.4 \times 5 = 2.0$ volt

## ILLUSTRATION 4.15

Three resistors of 2Ω, 3Ω and 4Ω are connected in (i) series, (ii) parallel. Find the equivalent resistance in each case.

**SOLUTION :**

Given $R_1 = 2\Omega$, $R_2 = 3\Omega$ and $R_3 = 4\Omega$

(i) In series, the equivalent resistance is

$$R = R_1 + R_2 + R_3 = 2+3+4 = 9\Omega.$$

(ii) In parallel, the equivalent resistance is $R$, then

$$\frac{1}{R} = \frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3} \quad \text{or} \quad \frac{1}{R} = \frac{1}{2}+\frac{1}{3}+\frac{1}{4} = \frac{13}{12} \quad \text{or} \quad \frac{1}{R} = \frac{1}{2}+\frac{1}{3}+\frac{1}{4} = \frac{13}{12}$$

**ILLUSTRATION 4.16**

Two resistors of $4\Omega$ and $6\Omega$ are connected in parallel. The combination is connected across a $6V$ battery of negligible resistance. Calculate : (i) the current through the battery (ii) through each resistor. Draw the circuit diagram.

**SOLUTION :**

The circuit diagram is shown in figure.

(i) If resistance of the combination is $R$, then

$$\frac{1}{R}=\frac{1}{4}+\frac{1}{6}=\frac{3+2}{12}=\frac{5}{12}$$

or $$R=\frac{12}{5}\Omega=2.4\,\Omega$$

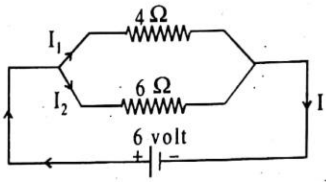


Fig. 4.26

Let current through the battery be $I$.

$$I=\frac{V}{R}=\frac{6}{2.4}=2.5\,A$$

(ii) The potential difference across each resistor is $V = 6$ volt (same as of battery) since they are in parallel.

Current through $4\Omega$ resistor, $I_1=\frac{V}{R_1}=\frac{6}{4}=1.5\,A$

Current through $6\Omega$ resistor, $I_2=\frac{V}{R_2}=\frac{6}{6}=1\,A$

**ILLUSTRATION 4.17**

$6\Omega$ and $3\Omega$ resistors are connected in parallel and an $8\Omega$ resistor is connected in series with them. A current of 2A passes through the $8\Omega$ resistor. Find

(a) the combined resistance

(b) the potential difference across the combined resistor

(c) the current through the $3\Omega$ resistor

**SOLUTION :**

Find the combined resistance $R$ of the resistors in parallel.

$R=?,\ R_1=6\Omega, R_2=3\Omega,$

$$\frac{1}{R}=\frac{1}{R_1}+\frac{1}{R_2}=\frac{1}{6}+\frac{1}{3}=\frac{3}{6}=\frac{1}{2}$$

$R=2\Omega$

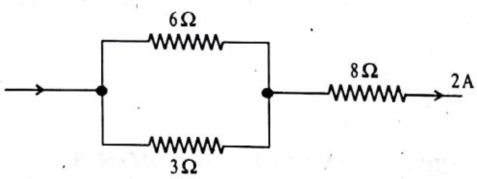


Fig. 4.27 (a)

The equivalent circuit is shown in Fig. 4.27 (b).

Fig. 4.27 (b)

(a) Let the combined resistance of all three resistors be $R$

$R=?,\ R_1=8\Omega, R_2=2\Omega$

$R=R_1+R_2=8\Omega+8\Omega=10\Omega$

(b) Let the potential difference across the combined resistors be $V$.

$V=?,\ I=2A,\ R=10\Omega$

$V=I\times R=2A\times 10\Omega=20V$

(c) The combined resistance of the parallel network is $2\Omega$. Hence potential difference $V$ across the parallel resistor is

$V=I\times R=2A\times 2\Omega=40V$

For the $3\Omega$ resistor $V=4V,\ I=?,\ R=3\Omega$

$$I=\frac{V}{R}=\frac{4V}{3\Omega}=1\frac{1}{3}A$$

**ILLUSTRATION 4.18**

Three resistors are connected in series to 24 volt battery, and an ammeter in the circuit reads 0.50 amperes. The first resistor is rated at 22 ohms, and the second at 8 ohms. Find (a) the total resistance (b) the resistance of the third resistor, and (c) the potential difference across the third resistor.

**SOLUTION:**

(a) The total resistance of the circuit is

$$R = \frac{\Delta V}{I} = \frac{24V}{0.50\ A} = 48\ \Omega$$

(b) In a series circuit, resistance add, so $22\ \Omega + 8\Omega + R_3 = 48\Omega$ and $R_3 = 18\Omega$.

(c) For any circuit element, $\Delta V = IR$ so $V_3 = (0.50\,A)\,(18\ \Omega) = 9V$

**ILLUSTRATION 4.19**

In the circuit shown, find :

(a) the equivalent resistance between points A and B.

(b) the current through the battery.

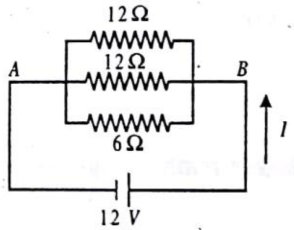


Fig. 4.28

**SOLUTION:**

Given : $R_1 = 12\Omega,\ R_2 = 12\Omega,\ R_3 = 6.0\ \Omega,\ V = 12V$

Find : (a) $R_p$ (b) $I$

(a) The three resistors are in a parallel combination.

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{12\Omega} + \frac{1}{12\Omega} + \frac{1}{6.0\Omega} = \frac{1}{12\Omega} + \frac{1}{12\Omega} + \frac{2}{12\Omega} = \frac{4}{12\Omega} = \frac{1}{3.0\Omega}$$

So, $R_p = 3.0\,\Omega$.

Or using $R_p = \frac{RR}{R+R} = \frac{R}{2}$ for the two 12 ohm resistors in parallel, $R_p = \frac{12\Omega}{2} = 6\Omega$

Now the two 6.0 Ω resistances are in parallel and the equivalent resistance is $R_p = \frac{6.0\ \Omega}{2} = 3.0\ \Omega$

(b) From Ohm's law, $I = \frac{V}{R} = \frac{V}{R_p} = \frac{12V}{3.0\Omega} = 4.0A$

## ELECTRICAL MEASURING INSTRUMENTS

### Galvanometer

A galvanometer is an instrument which is used to measure current or voltage, as per requirement.

### Ammeter

An ammeter is a low resistance galvanometer used to measure strength of current in an electrical circuit.

An ammeter is always connected in series in a circuit because when an ammeter is connected in series it does not appreciably change the resistance of circuit and hence the main current flowing through the circuit. An ideal ammeter has zero resistance.

The reading of an ammeter is always less than actual current in the circuit because all practical ammeters have low finite resistance.

Smaller is the resistance of an ammeter more accurate will be the reading.

A galvanometer can be converted to an ammeter by connecting a low resistance shunt in parallel to coil of galvanometer.

Here $I_g G = (I - I_g) S$ or $S = \frac{I_g}{I - I_g} G$

Here G is resistance of galvanometer and $I_g$ is current required to produce full scale deflection of current.

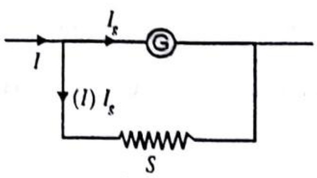


Fig. 4.29

**Shunt (S)**

It is a low resistance connected in parallel to coil of galvanometer to convert it to ammeter. It protects a galvanometer from strong currents. It is also used to alter range of an ammeter.

The resistance of converted ammeter is $R_A = \dfrac{G.S}{G+S}$

The range of an ammeter is increased by reducing shunt resistance $S$.

If $I = NI_g$ then $S = \dfrac{I_g}{NI_g - I_g}G = \dfrac{G}{N-1}$

The range of an ammeter can be increased N times by reducing shunt to $S = G/N\text{-}1$.

It is possible to increase the range of an ammeter because it lowers the resistance of ammeter further.

The length of the shunt required $\ell = \pi r^2 S/\rho$ where $r$ is radius of shunt wire and ρ is specific resistance of material of shunt wire.

Reducing the shunt resistance may increase range but it reduces the sensitivity.

**Voltmeter**

A voltmeter is a high resistance galvanometer used to measure potential difference.

A voltmeter is connected in parallel to a circuit element because when connected in parallel it draws least current from the main current. So it measures nearly accurate potential difference.

An ideal voltmeter has infinite resistance.

The reading of a voltmeter is always less than actual value because all practical voltmeter may have large but finite resistance.

Greater is the resistance of voltmeter more accurate is its reading.

A galvanometer can be converted to a voltmeter by connecting a high resistance in series with coil of galvanometer.

$V = I_g(R+G)$ or $R = \dfrac{V}{I_g} - G$

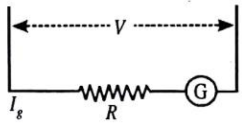



Fig. 4.30

The resistance of converted voltmeter is $R_v = R + G$

The range of a voltmeter is increased by increasing the series resistance.

If $V = NV_g = NI_g G$ then $R = \dfrac{NI_g G - G}{I_g} = (N-1)G$

The value of resistance required to increase range $N$ times is $R = (N-1)G$

## KIRCHHOFF'S LAW

This law is used to solve a problem regarding electrical circuit. The law has two parts.

**(a) Kirchhoff's first law or current law or junction rule**

In any electrical network, the algebraic sum of currents meeting at a junction is always zero i.e. $\Sigma I = 0$

$I_1 - I_2 + I_3 + I_4 - I_5 = 0$ or $I_1 + I_3 + I_4 = I_2 + I_5$

The sum of currents flowing towards a junction is equal to sum of currents leaving the junction.

By convention the current directed towards the junction is positive while those directed away from the junction is taken as negative.

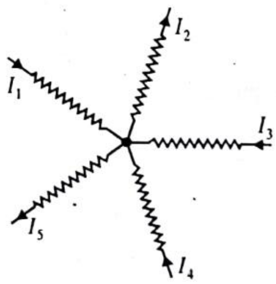



Fig. 4.31

The first law is in accordance with conservation of charge.

The charges do not accumulate at a junction. The total charge entering a junction is equal to total charge leaving the junction.

**(b) Kirchhoff's second law or voltage law or loop rule**

The algebraic sum of all the potential drops and emf's along any closed path in a network is zero. i.e. $\Sigma V = 0$

The second law is in accordance with conservation of energy.

According to second law, the electric energy given to the charge by a source of emf is lost in passing through resistance.

The change in potential in covering a resistance in the direction of current is negative $(-IR)$ while in opposite direction it is positive.


$V_A - IR = V_B$ $\qquad$ $V_B + IR = V_A$

$V_B - V_A = IR$ $\qquad$ $V_A - V_B = IR$

(a) $\qquad$ (b)

*Fig. 4.32*

The potential falls along direction of current. The potential fall is taken as negative while potential rise is taken as positive. The emf of source is taken as positive when it is traversed from negative to positive terminal while it is taken as negative when it is traversed from positive to negative irrespective of the direction of current.


$V_A - E = V_B$ $\qquad$ $V_B + E = V_A$

$V_B - V_A = -E$ $\qquad$ $V_A - V_B = E$

(a) $\qquad$ (b)

*Fig. 4.33*

If there are $n$ loops their will be $(n - 1)$ equations according to loop rule.

The algebraic sum of products of currents and resistances in a closed loop is equal to sum of emf's applied in the circuit i.e., $\Sigma E = \Sigma IR$.

**ILLUSTRATION 4.20**

Determine the current through the dc source in the following network:

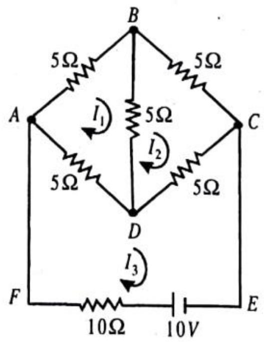



*Fig. 4.34*

**SOLUTION :**

We assume the loop, or mush, currents $I_1$, $I_2$ and $I_3$ in the loops, or meshes, *ABDA*, *BCDB* and *ADCEFA*, respectively, and arbitrarily select their directions clockwise, as shown, and traversal direction also clockwise. Applying the Kirchhoff's voltage law to the three loops, we have respectively,

$$+I_1 \times 10 + (I_1 - I_3)\,5 + (I_1 - I_3)\,5 = 0 \Rightarrow 4I_1 - I_2 = I_3 \qquad .....(1)$$

$$+I_2 \times 5 + (I_2 - I_3)\,10 + (I_2 - I_1)\,5 = 0 \Rightarrow -I_1 + 4I_2 = 2I_3 \qquad ....(2)$$

$$+(I_3 - I_1)\,5 + (I_3 - I_2)\,10 + I_3 \times 10 = 10 \Rightarrow -I_1 - 2I_2 + 5I_3 = 2 \qquad ....(3)$$

Solving the equations (1) and (2), we get

$$I_1 = \frac{2I_3}{5},\ I_2 = \frac{3I_3}{5}$$

Then, substituting these values of $I_1$ and $I_2$ into the equation (3), we get the current through the dc source, i.e.,

$$I_3 = \frac{10}{17}\,A.$$

**ILLUSTRATION – 4.21**

Calculate the current in each resistance in the given circuit.

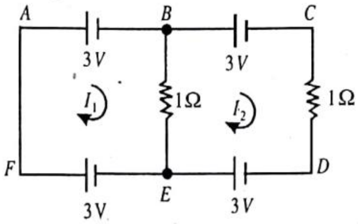



*Fig. 4.35*

**SOLUTION:**

Let us assume the loop currents $I_1$ and $I_2$ in the clockwise direction in the two meshes *ABEFA* and *BCDEB*, respectively. Let us also assume the traversal direction in the clockwise sense. Then, the equations for the two loops are, respectively,

$$(I_1 - I_2) \times 1 = +3 - 3 \Rightarrow I_1 = I_2$$

The current in the resistance of 1Ω between *B* and *E* is

$$I_{BE} = I_1 - I_2 = 0$$

## Knowledge ENHANCER

**Wheatstone Bridge**

It is an arrangement of four resistances devised by Charles Wheatstone which is used to measure an unknown resistance.

The Wheatstone bridge principle states that if four resistances *P*, *Q*, *R* and *S* are arranged to form a bridge with a cell and key between *A* and *C*, and a galvanometer between *B* and *D* then bridge is said to be balanced when galvanometer shows a zero deflection.

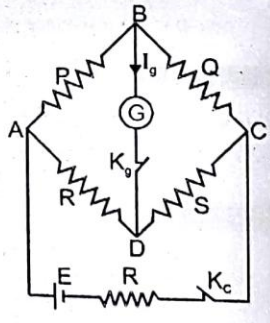



*Fig. 4.36*

In balanced condition $I_g = 0$ so $V_B = V_D$ or $\frac{P}{Q} = \frac{R}{S}$. This is called condition of balance.

The condition of balance depends on resistance *P*, *Q*, *R* and *S*. This is independent of emf of battery.

In state of balance the cell and galvanometer can be interchanged.

While performing an experiment at start press the cell key $K_c$ first and then the galvanometer key $K_g$ and at end remove $K_g$ first and then $K_c$ to avoid induced effects.

*P* and *Q* are called ratio arms, *R* is known as resistance arm and *S* is the unknown arm. *BD* and *AC* are called conjugate arms.

The resistance of balanced Wheatstone bridge between *A* and *C* is $\frac{(P+Q)(R+S)}{P+Q+R+S}$.

The sensitivity of bridge depends upon value of resistances. The sensitivity is maximum when P, Q, R and S are of same order.

**Unbalanced Wheatstone bridge**

In unbalanced bridge $I_g \neq 0$, $V_B \neq V_D$ so $\frac{P}{Q} \neq \frac{R}{S}$.

If $\frac{P}{Q} < \frac{R}{S}$ then $V_B > V_D$ so current flows from *B* to *D*.

If $\frac{P}{Q} > \frac{R}{S}$ then $V_B < V_D$ so current flows from *D* to *B*.

## METRE BRIDGE

The metre bridge, shown, is a practical arrangement of the Wheatstone's bridge. It consists of a 1m-long resistance wire $AC$ of the uniform cross-sectional area and uniform material, i.e., magnanin, or constantan, having the high electrical resistivity of low temperature coefficient.

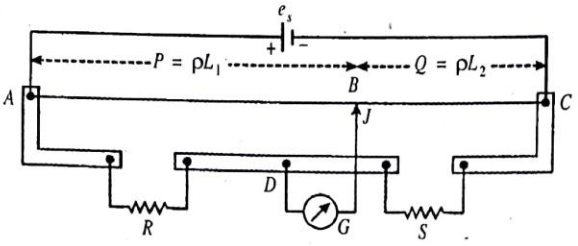



*Fig. 4.37 : Metre Bridge*

A null situation is obtained by moving the jockey $J$ on the bridge wire $AC$ till no deflection is observed in the galvanometer. Now, the balance condition gives

$$\frac{R}{S}=\frac{P}{Q} \Rightarrow \frac{R}{S}=\frac{\rho L_1}{\rho L_2}$$

$$\Rightarrow \frac{R}{S}=\frac{L_1}{L_2}$$

$$\Rightarrow \frac{R}{S}=\frac{L_1}{(1-L_1)}$$

where $\rho$ is the resistance per unit length of the bridge wire.

**ILLUSTRATION 4.22**

If the current through the branch $BD$ of the circuit, shown, is zero. Find the resistance $R$ and current through it.

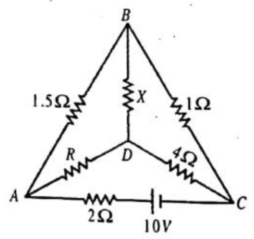



*Fig. 4.38*

**SOLUTION:**

The given circuit, when rearranged, is found to be a Wheatstone's bridge circuit, as shown.

Since, the current through the branch $BD$ is zero, the bridge is balanced, i.e.,

$$\frac{P}{Q}=\frac{R}{S} \Rightarrow \frac{1.5}{1}=\frac{R}{4}$$

$$\Rightarrow R = 4\times1.5 = 6\Omega$$

The branch $BD$ is ineffective as it carries no current and, therefore, we have two parallel paths $ABC$ and $ADC$ of the resistances $2.5\Omega$ and $10\Omega$, respectively. The combined resistance between $A$ and $C$ becomes

$$R_{AC}=\frac{2.5\times10}{(2.5+10)}=\frac{25}{12.5}=2\Omega$$

Further, this resistance is connected in series with the resistance of $2\Omega$ so that the total resistance becomes $(2 + 2) = 4\Omega$. The current from the source is

$$I=\frac{10}{4}=2.5A$$

Then, the current through the resistance $R$ is given by

$$I_R\times(R+4)=I\times(R_{AC})$$

$$I_R\times(6+4)=2.5\times2$$

$$I_R=\frac{2.5\times2}{10}=0.5A.$$

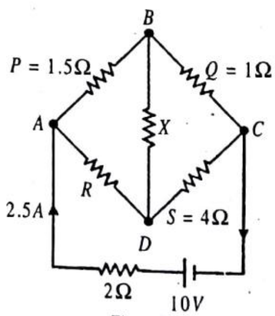



*Fig. 4.39*

## ILLUSTRATION 4.23

A metre bridge circuit is shown in the balanced state. The bridge wire $AC$ has a resistance per metre $\rho = 100\Omega/m$. Calculate the unknown resistance $S$ and the current drawn from the dc source of emf of 6 $V$ and negligible internal resistance.

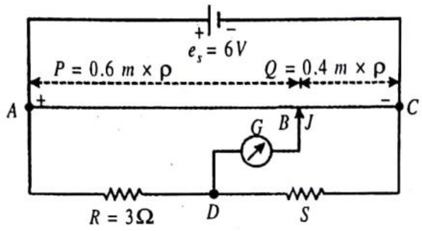



*Fig. 4.40*

## SOLUTION :

From the balance condition, we have

$$\frac{P}{Q} = \frac{R}{S} \Rightarrow \frac{0.6\times100}{0.4\times100} = \frac{3}{S}$$

$$\Rightarrow S = \frac{4\times3}{6} = 2\Omega$$

The equivalent resistance between A and C is given by

$$R_{AC} = \frac{(P+Q)(R+S)}{(P+Q)+(R+S)} = \frac{(1\times100)(3+2)}{(1\times100)+(3+2)}$$

$$= \frac{100\times5}{100+5} = \frac{500}{105}\Omega$$

Then, the current drawn from the dc source is

$$I = \frac{6}{R_{AC}} = \frac{6\times105}{500} = \frac{630}{500} = 1.26A$$

# MISCELLANEOUS SOLVED EXAMPLES

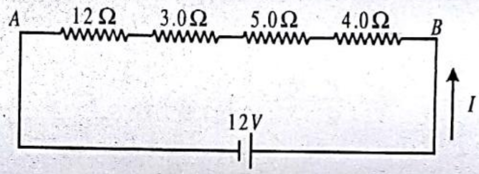
**1. If $3.0 \times 10^{15}$ electrons flow through a section of a wire of diameter 2.0 mm in 4.0 s, what is the electric current in the wire?**

**Sol.** Given $n = 3.0 \times 10^{15}$ electrons, $t = 4.0\ s$, $d = 2.0$ mm.

The charge in $3.0 \times 10^{15}$ electrons is $q = ne = (3.0 \times 10^{15}$ electrons$)(1.60 \times 10^{-19}$ C/electrons$) = 4.8 \times 10^{-4}$

So, $I = \frac{q}{t} = \frac{4.8 \times 10^4 C}{4.0\ s} = 1.2 \times 10^4 A = 0.12$ mA

**2. In the circuit shown, find : (a) the equivalent resistance between points A and B, (b) the current through each resistor.**




**Sol.** Given : $R_1 = 12\,\Omega$, $R_2 = 3.0\,\Omega$, $R_3 = 5.0\,\Omega$, $R_4 = 4.0\,\Omega$, $V = 12V$.

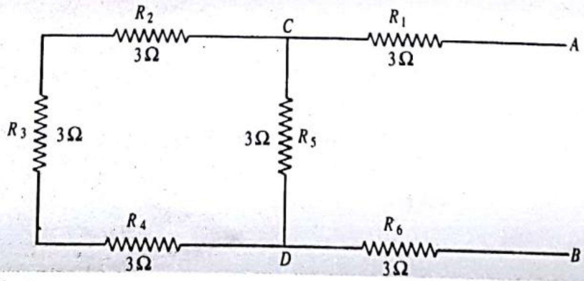
(a) All four resistors are in series combination, so

$$R_s = R_1 + R_2 + R_3 + R_4 = 12\Omega + 3.0\Omega + 5.0\Omega + 4.0\Omega = 24\Omega$$

(b) The current through all resistors in series is the same

$$I = \frac{V}{R} = \frac{V}{R_s} = \frac{12V}{24\Omega} = 0.50\ A$$

**3. For the combination of resistors shown in figure, find the equivalent resistance between (i) C and D (ii) A and B.**




**Sol.** (i) The resistors $R_2$, $R_3$, $R_4$ are in series. They can be replaced by an equivalent resistance $R'$, where

$R' = R_2 + R_3 + R_4 = 3 + 3 + 3 = 9\Omega$.

The resistance $R_5$ (= 3Ω) and $R'$ (= 9Ω) are in parallel, between the points $C$ and $D$. The equivalent resistance between $C$ and $D$ is $R''$, where $\frac{1}{R''} = \frac{1}{3} + \frac{1}{9}$ or $\frac{1}{R''} = \frac{3+1}{9} = \frac{4}{9}$ or $\frac{1}{R''} = \frac{4}{9} = 2.25\ \Omega$

Thus the equivalent resistance between $C$ and $D$ is 2.25 Ω

(ii) Now the resistor $R1 = (3\Omega)$. $R''$ (= 2.25Ω) and $R_6$ (= 3Ω) are in series between the points $A$ and $B$. The equivalent resistance between $A$ and $B$ is : $R = R_1 + R'' + R_6 = 3 + 2.25 + 3 = 8.25\Omega$

**4. Two copper wires $A$ and $B$ of length 30 m and 10 m have radius 2 mm and 1 mm respectively. Compare the resistance of the two wires. Which will have less resistance ?**

**Sol.** From the relation $R = \rho\frac{\ell}{A}$

Resistance of wire $A$ is $R_A = \rho\frac{30}{\pi(2\times10^{-3})^2}$

Resistance of wire $B$ is $R_B = \rho\frac{10}{\pi(1\times10^{-3})^2}$

On dividing $\frac{R_A}{R_B} = \frac{30}{10}\left(\frac{1\times10^{-3}}{2\times10^{-3}}\right)^2 = \frac{3}{4}$

Thus the wire $A$ has less resistance.

**5. How much energy is given to each coulomb of charge passing through a 6 V battery ?**

**Sol.** Energy = charge × potential difference

$= 1 \times 6 = 6$ joule

**6. (a) How much current will an electric bulb draw from a 220 $V$ source, if the resistance of the bulb filament is 1200 Ω ?**

**(b) How much current will an electric heater coil draw from a 220 $V$ source, if the resistance of the heater coil is 100 Ω?**

**Sol.** (a) We are given $V = 220\ V$; $R = 1200\ \Omega$.

From Eq. $R = V/I$, we have the current $I = 220\ V/1200\ \Omega = 0.18\ A$.

(b) We are given, $V = 220\ V$, $R = 100\ \Omega$.

From Eq. $R = V/I$, we have the current $I = 220\ V/100\ \Omega = 2.2\ A$.

The difference of current drawn by an electric bulb and electric heater from the same 220 $V$ source.

**7. Resistance of a metal wire of length 1 m is 26 Ω at 20°C. If the diameter of the wire is 0.3 mm, what will be the resistivity of the metal at that temperature?**

**Sol.** We are given the resistance $R$ of the wire = 26 Ω, the diameter $d$ = 0.3 mm = $3 \times 10^{-4}$ m, and the length $l$ of the wire = 1 m.

Therefore, from the resistivity of the given metallic wire is $\rho = (RA/l) = (R\pi d^2/4l)$

Substitution of values in this gives $\rho = 1.84 \times 10^{-8}\ \Omega\,m$

The resistivity of the metal at 20°C is $1.84 \times 10^{-8}\ \Omega$ m. This is the resistivity of manganese.

**8. An electric lamp of 100 Ω, a toaster of resistance 50 Ω, and a water filter of resistance 500 Ω are connected in parallel to a 220V source. What is the resistance of an electric iron connected to the same source that takes as much current as all three appliances, and what is the current through it?**

**Sol.** $R_l = 100\ \Omega, R_t = 50\ \Omega,\ R_f = 500\Omega,\ V = 220$ volt,

$I$ drawn by, lamp = $I_l = \frac{V}{R_l} = \frac{220}{100} = 2.2A$

toaster = $I_t = \frac{220}{50} = 4.4A$, water filter = $I_f = \frac{220}{500} = 0.44A$

Total current drawn = 7.04 A

Current to be drawn by iron = 7.04 A

Resistance of electric iron = $R_1 = \frac{V}{I} = \frac{220}{7.04} = 31.25\Omega$

**9. What is (a) the highest, (b) the lowest total resistance that can be secured by combinations of four coils of resistance 4 Ω, 8 Ω, 12 Ω, 24 Ω ?**

**Sol.** (a) Highest – By connecting the resistors in series. So $R = 4 + 8 + 12 + 24 = 48\ \Omega$

(b) Lowest – By connecting the resistors in parallel.

So, $R = \frac{64}{6+3+2+1} = \frac{24}{12} = 2\Omega$

**10. How many 176Ω resistors (in parallel) are required to carry 5 A on a 220 $V$ line?**

**Sol.** When $N$ resistors each $R\ \Omega$ are in parallel.

$$R_p = \frac{R}{N}$$

Current drawn from cell = $I = \frac{V}{R_{eq}} = \frac{VN}{R}$

$\therefore \quad N = \frac{IR}{V} = \frac{5\times176}{220} = 4$

**11. A nichrome wire has a resistance of 10Ω. Find the resistance of another nichrome wire, whose length is three times and area of cross-section four times the first wire.**

**Sol.** **Case 1 :** $R = 10\ \Omega$. Let $\ell$ be length and '$a$' the area of cross-section.

$\therefore \quad R = \rho\frac{\ell}{a}$ or $10 = \rho\frac{\ell}{a}$ ......... (1)

**Case 2 :** $R_1 = ?$, length $3\ell$, area $= 4a$

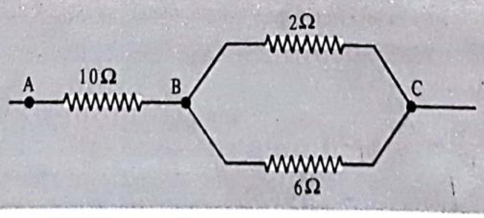
$\therefore \quad R_1 = \rho\frac{3\ell}{4a}$ ......... (2)

Dividing (2) by (1)

$$\frac{R_1}{10} = \frac{\rho.3\ell}{4a} \times \frac{a}{\rho.\ell}$$

$\therefore \quad R_1 = 10 \times \frac{3}{4} = 7.5\ \Omega$

**12. Calculate the equivalent resistance between points $A$ and $C$, as shown in figure.**



**Sol.** Resistance of 2Ω and 6Ω are connected in parallel between points $B$ and $C$. Let $R_p$ be their equivalent resistance.

$$\frac{1}{R_p}=\frac{1}{2}+\frac{1}{6}=\frac{4}{6}=\frac{2}{3} \quad \text{or} \quad R_p=\frac{3}{2}=1.5\,\Omega$$

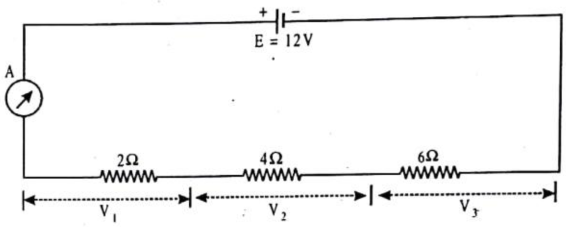
Now, equivalent resistance $R_p$ is in series with 10Ω resistance. Therefore, equivalent resistance of circuit ($R_s$) is

$\therefore \quad R_s = 10 + 1.5 = 11.5\Omega.$

**13. Three resistors of 2Ω, 4Ω and 6Ω are connected in series to a battery of emf 12V and negligible internal resistance. Draw the circuit diagram and calculate (i) current drawn from cell (ii) p.d. at the ends of each resistor.**

**Sol.** Resistance of 2Ω, 4Ω and 6Ω in series.

$R = 2 + 4 + 6 = 12\Omega$




(i) $\therefore$ Current drawn from cell $(I)=\dfrac{V}{R}=\dfrac{12}{12}=1A$

(ii) P.D. across 2Ω resistor $V_1 = I.R = 1\times 2 = 2V$

P.D. across 4Ω resistor $V_2 = I.R = 1\times 4 = 4V$

P.D. across 6Ω resistor $V_3 = I.R = 1\times 6 = 6V$

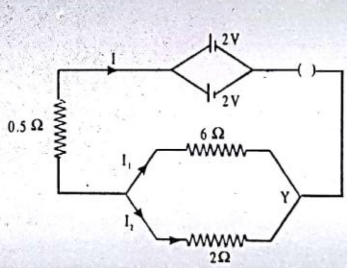
**14. Two cells of 2V each are connected in parallel. (figure) An external resistance of 0.5Ω is connected in series to the junction of two parallel resistors of 6Ω and 2Ω and then to the common terminal of the battery through each resistor.**

**Calculate the**

**(i) total resistance of the circuit.**

**(ii) current flowing through 0.5Ω resistors**

**(iii) current flowing through 6Ω resistor.**




**Sol.** EMF of the battery = $2V$

Effective resistance of the parallel resistors is given by $R_1$.

$$\frac{1}{R_1}=\frac{1}{6}+\frac{1}{2}=\frac{1+3}{6}=\frac{4}{6}=\frac{2}{3} \Rightarrow R_1=\frac{3}{2}=1.5\,\Omega$$

(i) Total resistance of the circuit, $R = 1.5 + 0.5 = 2\Omega$

Main current $I=\dfrac{V}{R}=\dfrac{2}{2}=1A$

(ii) Current flowing through 0.5Ω coil = 1A

P.D. across the junctions : $V_1 = IR_1 = 1\times 1.5 = 1.5V$

(iii) Hence, current $I_1$, flowing through 6Ω resistor $I_1=\dfrac{V_1}{6}=\dfrac{1.5}{6}=0.25\,A$

**15. Four cells each of emf $2V$ and internal resistance 0.1 Ω are connected in series. The combination in series is joined to an ammeter of negligible resistance, a 1.6Ω resistor and an unknown resistor $R_1$. The current in the circuit is $2A$. Draw a labelled diagram for the above arrangement and calculate :**

**(i) the total resistance in the circuit (ii) the total emf (iii) the value of $R_1$ (iv) the potential difference across $R_1$.**

**Sol.** The circuit diagram is shown in figure.

(i) Total internal resistance $= 0.1 + 0.1 + 0.1 + 0.1 = 0.4\,\Omega$.
Total resistance in the circuit $= 1.6 + R_1 + 0.4 = (2.0 + R_1)\,\Omega$.

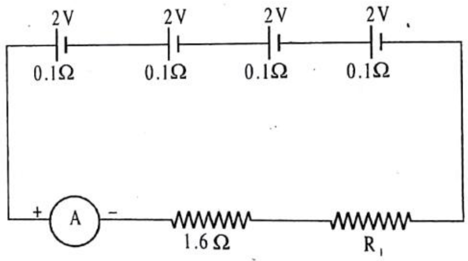
(ii) Total emf $= 2 + 2 + 2 + 2 = 8V$

(iii) Current in circuit $= \dfrac{\text{Total emf}}{\text{Total resistance}}$

$\therefore\ 2 = \dfrac{8}{(2.0 + R_1)}$ or $4 + 2R_1 = 8$

$2R_1 = 8 - 4 = 4$ or $R_1 = 2\Omega$.

(iv) Potential difference across $R_1$ is $V = IR_1 = 2 \times 2 = 4V$



# 1 EXERCISE

## FIB Fill in the Blanks :

**DIRECTIONS :** *Complete the following statements with an appropriate word / term to be filled in the blank space(s).*

1. The colour coding of wires is ................ for earth .......... for live and ............... for neutral.
2. The rate of flow of electric charge is called .................
3. Current is measured with an instrument called a (an).................
4. If there is no current, a voltmeter connected across a resistor will register..................... voltage.
5. Between any two points in a circuit, the sum of all ........... is the same through any pathway.
6. Combined resistance is the sum of separate resistances provided that the various conductors are connected in ..........
7. In a parallel circuit, each circuit element has the same ....................
8. Copper is a preferred material for making wire because of its low........................
9. The SI unit of electric current is ..............
10. .............. is a property that resists the flow of electrons in a conductor.
11. The SI unit of resistance is .................
12. The potential difference across the ends of a resistor is ............... to the current through it, provided its .................... remains the same.
13. The resistance of a conductor depends directly on its ............., inversely on its ................., and also on the ............. of the conductor.
14. The slope of voltage (along y-axis) and current (along x-axis) is called .............
15. An ammeter should have very ......................... resistance.
16. Current is measured by an instrument called ...............
17. The phenomenon of losing of electrical resistance by a conductor on cooling it to an extremely low temperature is known as ..................

## T/F True / False :

**DIRECTIONS :** *Read the following statements and write your answer as true or false.*

1. A copper wire of length $L$ and cross-sectional area $A$ carries a current $I$. If the specific resistance of copper is $S$, then electric field in the wire is $IS/A$.
2. The drift velocity of electrons in a metallic wire will decrease if the temperature of the wire is increased.
3. Two wires, each of radius $r$, but of different materials are connected together end to end. If the densities of charge carriers in the two wires are in the ratio 1 : 4, the drift velocity of electrons in the two wires will be in the ratio 1 : 2.
4. The drift velocity of an electron is doubled if the applied electric field across the conductor is doubled.
5. The temperature coefficient of resistance of a wire is 0.00125/°C. The resistance of the wire is 1 ohm at 300 K. The resistance will be 2 ohm at 1100 K.
6. The quantity of charge flowing past a point multiplied by time is a current.
7. The resistivity of all pure metals increases with the rise in temperature.
8. Ohm's law is a relation between the power used in a circuit to the current and the potential difference.
9. Direction of current is taken opposite to the direction of flow of electrons.
10. A cell generates a potential difference across its terminals
11. The equivalent resistance of several resistors in series is equal to the sum of their individual resistances.
12. In parallel combination, the reciprocal of equivalent resistance is the sum of the reciprocal of individual resistance.
13. A voltmeter is always connected in series in the circuit to measure the potential difference between two points.
14. The resistivity of an alloy is generally lower than that of pure metals which form the alloy.
15. The series arrangement is used for domestic circuits.

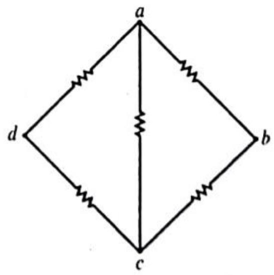
## MTF Match the Following :

**DIRECTIONS :** *Each question contains statements given in two columns which have to be matched. Statements (A, B, C, D) in column I have to be matched with statements (p, q, r, s) in column II.*

1.

| Column I | Column II |
|---|---|
| (A) Ohm | (p) $\dfrac{\rho L}{A}$ |
| (B) Resistance | (q) $\dfrac{1 \text{ volt}}{1 \text{ ampere}}$ |
| (C) Resistivity | (r) zero resistance |
| (D) Super conductor | (s) ohm-meter |

2. In the figure shown, the value of each resistance is R. match the entries of column I with the entries of column II.



| Column I | Column II |
|---|---|
| (A) Resistance between $a$ and $b$ | (p) $R/2$ |
| (B) Resistance between $a$ and $c$ | (q) $\frac{5}{8}R$ |
| (C) Resistance between $b$ and $d$ | (r) $R$ |
| | (s) None |

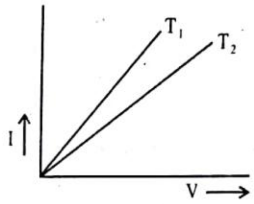
3. Column II gives order of resistivity for materials in column I

| Column I | Column II |
|---|---|
| (A) Semi-conductor | (p) $3 \times 10^3\ \Omega$-m |
| (B) Conductor | (q) $10^{-8}\ \Omega$-m |
| (C) Insulator | (r) $10^{16}\ \Omega$-m |
| (D) Super conductor | (s) $1\ \Omega$-m |

## VSAQ Very Short Answer Questions :

**DIRECTIONS :** *Give answer in one word or one sentence.*

1. What are the factors on which resistance depends?
2. Which combination have maximum value of equivalent resistance?
3. If one coulomb charge flows in a circuit for one second then what will be the value of current in the circuit.
4. Define one ohm resistance.
5. Name the instrument used to measure electric current.
6. Write the unit of electrical resistance.
7. Name the best conductor of electricity.
8. In domestic wiring do we connect various distribution circuits in series?
9. Why is an ammeter likely to be burnt out if you connect it in parallel?
10. What is the resistance of an air gap?
11. Manganin is used for making standard resistors. Why?
12. A wire of resistivity $\rho$ is stretched to double its length. What will be its new resistivity?
13. A copper wire of resistivity $\rho$ is stretched to reduce its diameter to half of its previous value. What will be its new resistivity?
14. Why is a voltmeter always connected in parallel with a circuit element across which voltage is to be measured?
15. Which physical quantity does the voltage vs current graph for a metallic conductor depict?
16. A carbon resistor of 74 k$\Omega$ is to be marked with rings of different colours for its identification. Write the sequence of colours.
17. Specific resistance of copper, silver and constant an are $1.18 \times 10^{-6}\ \Omega$ cm, $1 \times 10^{-6}\ \Omega$ cm and $48 \times 10^{-6}\ \Omega$ cm respectively. Which is the best electrical conductor and why?
18. Sketch a graph showing variation of resistivity of carbon with temperature.
19. Is a current-carrying wire electrically charged?
20. A wire has the non-uniform cross-sectional area. A steady current flows through the wire in the direction of increasing cross-sectional area. How does the drift speed of charge carrier change?
21. V-I graph for a metallic wire at two different temperatures $T_1$ and $T_2$ is as shown in the following figures. Which of the two temperature is higher and why?



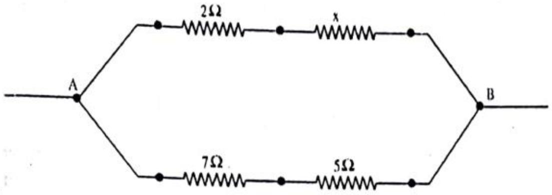

22. What is the effect on current through a circuit of steady resistance when both voltage and resistance are doubled?
23. Which has the greater electrical resistance, wet skin or dry skin?
24. What is the source of electrons that makes a shock when you touch a charged conductor?
25. A carbon resistor is marked in coloured bands of red, black, organge and silver. What is the resistance and tolerance value of the resistor?

## SQA Short Answer Questions :

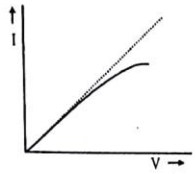
**DIRECTIONS :** *Give answer in 2-3 sentences.*

1. Write Ohm's law. Explain it by giving diagram of an electric circuit.
2. Write the expression for the equivalent resistance R of three resistors $R_1$, $R_2$ and $R_3$ joined in (i) parallel, (ii) series.
3. Define the term current and state its SI unit.
4. Define the term resistance.
5. A lamp draws a current of 0.5A when it is connected to a 230 V supply. What is the resistance of the filament of the lamp?
6. Join three resistances of 2 ohm each such that the total resistance of the circuit is 3 ohm.
7. Judge the equivalent resistance when the following are connected in parallel (a) 1 $\Omega$ and $10^6\ \Omega$ (b) 1$\Omega$ and $10^3\ \Omega$ and $10^6\ \Omega$.
8. Resistance of a metal wire of length 1m is 26$\Omega$ at 20°C. If the diameter of the wire is 0.3 mm, what will be the resistivity of the metal at that temperature.

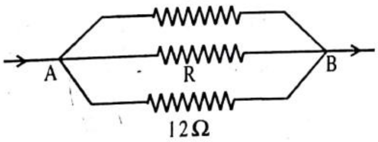
9. The equivalent resistance of circuit diagram is 4Ω. Calculate the resistance of $x$.




10. The $I$-$V$ characteristics of a resistor are observed to deviate from a straight line for higher values of current as shown below. Why?




11. A potential difference $V$ is applied across a copper wire of diameter $d$ and length $l$. When $d$ is doubled, how does the drift velocity change?
12. Why do electrons, rather than protons, make up the flow of charge in a metal wire?
13. Does electric charge flow *across* a circuit or *through* a circuit? Does voltage *flow* across a circuit or is it *impressed* across a circuit ? Explain.
14. Two resistors of 15Ω and 30Ω are connected in parallel. What resistance should be connected in series of the combination to get an equivalent resistance of 20Ω ?
15. The equivalent resistance between the point A and B in the adjoining circuit is 2 Ω. Determine the value of R.




## LAQ Long Answer Questions :

**DIRECTIONS :** *Give answer in four to five sentences.*

1. How does the resistance of a metallic wire depend on its temperature? Explain the reason to your answer.
2. A circuit consists of a 1Ω wire in series with a parallel arrangement of 6Ω and 3Ω with a P.D. of 12V is connected across the whole circuit. Draw the circuit diagram and calculate the main current in the circuit.
3. A copper wire has diameter 0.5 mm and resistivity of $1.6 \times 10^{-8}$ Ωm. What will be the length of this wire to make its resistance 10Ω ? How much does the resistance change if the diameter is doubled ?
4. Three resistors of 20 ohm, 30 ohms and 50 ohm resistance are joined in series. Across this combination a source of 150 volts is connected then determine the current in each resistor and potential difference across their ends.
5. When a potential difference of 2 volt is applied across the ends of a wire of 5m length, a current of 1A is found to flow through it. Calculate :
   (i) the resistance per unit length of the wire
   (ii) the resistance of 2m length of this wire
   (iii) the resistance across the ends of the wire it is doubled on itself.
6. How can three resistors of resistance 2Ω, 3Ω and 6Ω be connected to give a total resistance of (a) 4 Ω (b) 1 Ω?
7. A battery of 9V is connected in series with resistors of 0.2Ω, 0.3Ω, 0.4Ω, 0.5Ω and 12Ω respectively. How much current would flow through the 12Ω resistor?
8. What is drift velocity of electrons and relaxation time of free electrons in a metallic conductor carrying a current? Establish a relation between them?
9. Define resistivity of material. State its S.I. units and discuss its variation with temperature in case of (i) metals (ii) semiconductors and (iii) insulators.
10. Explain the various types of grouping of cells and find the condition for the maximum current in the external resistor connected to the combination of cells (i) in series (ii) in parallel and (iii) in mixed grouping.

# 2 EXERCISE

## Multiple Choice Questions :

**DIRECTIONS :** *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONLY ONE is correct.*

**1.** A cylindrical rod is reformed to twice its length with no change in its volume. If the resistance of the rod was $R$, the new resistance will be
(a) $R$ (b) $2R$
(c) $4R$ (d) $8R$

**2.** What is the current through a 5.0 ohm resistor if the voltage across it is $10V$
(a) zero (b) $0.50A$
(c) $2.0A$ (d) 5.0 A

**3.** A wire carries a steady current of 1.0 A over a period of 20s. What total charge passes through the wire in this time interval
(a) $200\,C$ (b) $20\,C$
(c) $2.0\,C$ (d) $0.20\,C$

**4.** The length of a wire is doubled and the radius is doubled. By what factor does the resistance change
(a) 4 times as large (b) twice as large
(c) unchanged (d) half as large

**5.** A circular conductor is made of a uniform wire of resistance $2\times10^{-3}$ ohm/metre and the diameter of this circular conductor is 2 metres. Then the resistance measured between the ends of the diameter is (in ohms)
(a) $\pi\times10^{-3}$ (b) $2\pi\times10^{-3}$
(c) $4\pi\times10^{-3}$ (d) $4\times10^{-3}$

**6.** A 24V potential difference is applied across a parallel combination of four 6 ohm resistor. The current in each resistor is
(a) 1 A (b) 4 A
(c) 16 A (d) 36 A

**7.** Three resistances of 2, 3 and $5\Omega$ are connected in parallel to a 10V battery of negligible internal resistance. The potential difference across the $3\Omega$ resistance will be
(a) 2V (b) 3V
(c) 5V (d) 10V

**8.** Two unequal resistances are connected in parallel. Which of the following statement is true
(a) current in same in both
(b) current is larger in higher resistance
(c) voltage-drop is same across both
(d) voltage-drop is lower in lower resistance

**9.** You are given $n$ identical wires, each of resistance R. When these are connected in parallel, the equivalent resistance is X. When these will be connected in series, then the equivalent resistance will be
(a) $X/n^2$ (b) $n^2X$
(c) $X/n$ (d) $nX$

**10.** A piece of wire of resistance R is cut into five equal parts. These parts are then connected in parallel. If the equivalent resistance of this combination is R', then the ratio R/R' is
(a) 1/25 (b) 1/5
(c) 5 (d) 25

**11.** 2 ampere current is flowing through a conductor from a 10 volt emf source then resistance of conductor is
(a) $20\,\Omega$ (b) $5\,\Omega$
(c) $12\,\Omega$ (d) $8\,\Omega$

**12.** Charge on an electron is $1.6\times10^{-19}$ coulomb. Number of electrons passing through the wire per second on flowing of 1 ampere current through the wire will be
(a) $0.625\times10^{-19}$ (b) $1.6\times10^{-19}$
(c) $1.6\times10^{-19}$ (d) $0.625\times10^{19}$

**13.** 20 coulomb charge is flowing in 0.5 second from a point in an electric circuit then value of electric current in amperes will be
(a) 10 (b) 40
(c) 0.005 (d) 0.05

**14.** Three resistors of $4.0\,\Omega$, $6.0\,\Omega$ and $10.0\,\Omega$ are connected in series. What is their equivalent resistance
(a) $20\,\Omega$ (b) $7.3\,\Omega$
(c) $6.0\,\Omega$ (d) $4.0\,\Omega$

**15.** A letter 'A' is constructed of a uniform wire of resistance 1 ohm per cm. The sides of the letter are 20 cm and the cross piece in the middle is 10 cm long. The resistance between the ends of the legs will be
(a) 32.4 ohm (b) 28.7 ohm
(c) 26.7 ohm (d) 24.7 ohm

**16.** A wire of resistance R is cut into ten equal parts which are then joined in parallel. The new resistance is
(a) 0.01 R (b) 0.1 R
(c) 10R (d) 100R

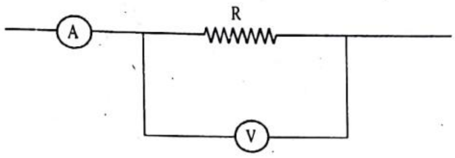
**17.** According to international convention of colour coding in a wire
(a) live is red, neutral is black and earth is green
(b) live is red, neutral is green and earth is black
(c) live is brown, neutral is blue and earth is black
(d) live is red, neutral is black and earth is green

**18.** If a wire is stretched to make its length three times, its resistance will become
(a) three times (b) one-third
(c) nine times (d) one-ninth

**19.** The resistivity of a wire depends on
(a) length
(b) area of cross-section
(c) material
(d) all the above three factors

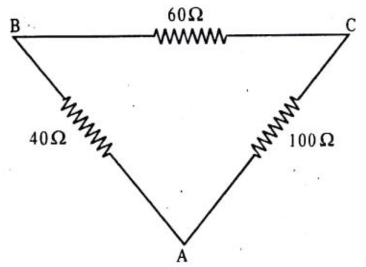
**20.** Ampere-second stands for the unit of
(a) power (b) charge
(c) e.m.f. (d) energy

**21.** In the circuits shown below the ammeter A reads 4 amp. and the voltmeter V reads 20 volts. The value of the resistance R is




(a) slightly more than 5 ohms
(b) slightly less than 5 ohms
(c) exactly 5 ohms
(d) None of the above

**22.** Three resistors are connected to form the sides of a triangle ABC as shown below.




The resistance of side AB is 40 ohms, of side BC 60 ohms and of side CA 100 ohms. The effective resistance between the point A and B in ohms is
(a) 50 (b) 64
(c) 32 (d) 100

**23.** If one micro-amp. current is flowing in a wire, the number of electrons which pass from one end of the wire to the other end in one second is
(a) $6.25\times10^{12}$ (b) $6.25\times10^{15}$
(c) $6.25\times10^{18}$ (d) $6.25\times10^{19}$

**24.** The unit for specific resistance is
(a) ohm × second (b) ohm × cm
(c) ohm (d) ohm/cm

**25.** If the temperature of a conductor is increased, its resistance will
(a) not increase
(b) increase
(c) decrease
(d) change according to the whether

**26.** The unit for electric conductivity is
(a) ohm per cm (b) ohm × cm
(c) ohm per second (d) mho

**27.** Two wires of resistance $R_1$ and $R_2$ are joined in parallel. The equivalent resistance of the combination is
(a) $R_1R_2/R_1+R_2$ (b) $R_1+R_2$
(c) $R_1\times R_2$ (d) $R_1/R_2$

**28.** Gases are good conductors of electricity at
(a) high pressure (b) low pressure
(c) low temperature (d) high temperature

**29.** The resistance of a thin wire in comparison of a thick wire of the same material
(a) is low
(b) is equal
(c) depends upon the metal of the wire
(d) is high

**30.** If the specific resistance of a wire of length $l$ and radius $r$ is $k$ then resistance is
(a) $k\pi r^2/l$ (b) $\pi r^2/lk$
(c) $kl/\pi r^2$ (d) $k/lr^2$

**31.** If a charge of $1.6\times10^{-19}$ coulomb flows per second through any cross section of any conductor, the current constitute will be
(a) $2.56\times10^{-19}$ A (b) $6.25\times10^{-19}$ A
(c) $1.6\times10^{-19}$ A (d) $3.2\times10^{-19}$ A

**32.** The number of electrons flowing per second through any cross section of wire, if it carries a current of one ampere, will be
(a) $2.5\times10^{18}$ (b) $6.25\times10^{18}$
(c) $12.5\times10^{18}$ (d) $5\times10^{18}$

**33.** The number of electron passing through a heater wire in one minute, if it carries a current of 8 ampere, will be
(a) $2\times10^{20}$ (b) $2\times10^{21}$
(c) $3\times10^{20}$ (d) $3\times10^{21}$

**34.** The total momentum of electrons in a straight wire of length $\ell = 1000$ m carrying a current $I = 70$ A, will be (in N. s)
(a) $0.40\times10^{-6}$ (b) $0.20\times10^{-6}$
(c) $0.80\times10^{-6}$ (d) $0.16\times10^{-6}$

**35.** In a wire of length 4m and diameter 6mm, a current of 120 ampere is passed. The potential difference across the wire is found to be 18 volt. The resistance of wire will be
(a) 0.15 ohm (b) 0.25 ohm
(c) 6.660 ohm (d) none of the above

**36.** The resistance between two rectangular faces of a block of dimensions 4 cm × 4 cm × 10 cm of maganin ($r = 48\times10^{-8}$ ohm, m), will be
(a) 4.8 μΩ (b) 3.8 μΩ
(c) 30 μΩ (d) 3 μΩ

**37.** If resistance of a wire formed by 1.cc of copper be 2.46Ω. The diameter of wire is 0.32 mm, then the specific resistance of wire will be
(a) $1.59\times10^{-6}$ ohm. cm (b) $2.32\times10^{-6}$ ohm. cm
(c) $3.59\times10^{-6}$ ohm. cm (d) $1.59\times10^{-8}$ ohm. cm

38. A given piece of wire length $\ell$, cross sectional area A and resistance R is stretched uniformly to a wire of length $2\ell$. The new resistance will be
(a) 2R (b) 4R
(c) R/2 (d) Remains unchanged

39. A given piece of wire of length $\ell$, radius $r$ and resistance R is stretched uniformly to a wire of radius $(r/2)$. The new resistances will be
(a) 2R (b) 4R
(c) 8R (d) 16R

40. There are two wires of the same length and of the same material and radial $r$ and $2r$. The ratio of their specific resistance is
(a) 1 : 2 (b) 1 : 1
(c) 1 : 4 (d) 4 : 1

41. Specific resistance of a wire depends on the
(a) length of the wire
(b) area of cross-section of the wire
(c) resistance of the wire
(d) material of the wire

42. The resistance of some substances become zero at very low temperature, then these substances are called
(a) good conductors (b) super conductors
(c) bad conductors (d) semi conductors

43. The resistance of wire is 20Ω. The wire is stretched to three time its length. Then the resistance will now be
(a) 6.67 Ω (b) 60 Ω
(c) 120 Ω (d) 180 Ω

44. When the resistance of copper wire is 0.1 Ω and the radius is 1 mm, then the length of the wire is (specific resistance of copper is $3.14 \times 10^{-8}$ ohm × m)
(a) 10 cm (b) 10 m
(c) 100 m (d) 100 cm

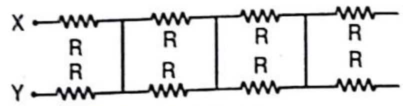
45. When the resistance wire is passed through a die the cross-section area decreases by 1%, the change in resistance of the wire is
(a) 1% decrease (b) 1% increase
(c) 2% decrease (d) 2% increase

46. Two wires of the same material having lengths in the ratio of 1 : 2 and diameters in the ratio 2 : 1 are connected with a cell of 6 volt and internal resistance 1Ω. The ratio of the potential difference across the two wires will be
(a) 1 : 2 (b) 2 : 1
(c) 1 : 8 (d) 8 : 1

47. The resistance 4R, 16R, 64R, ..........∞ are connected in series, their resultant will be
(a) 0 (b) ∞
(c) 4/3 R (d) 3/4 R

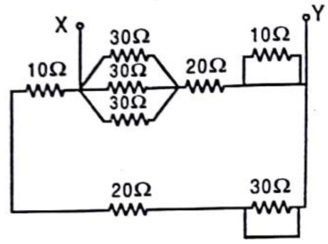
48. Resistance R, 2R, 4R, 8R ............. ∞ are connected in parallel. Their resultant resistance will be
(a) R (b) R/2
(c) 0 (d) ∞

49. The equivalent resistance between points X & Y



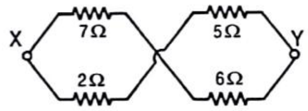

(a) R (b) 2R
(c) R/2 (d) 4R

50. The equivalent resistance between points X & Y




(a) 5Ω (b) 10 Ω
(c) 15 Ω (d) 60 Ω

51. The equivalent resistance between points X & Y




(a) 4Ω (b) 4.5 Ω
(c) 2 Ω (d) 20 Ω

52. Three resistances 4Ω each of are connected in the form of an equilateral triangle. The effective resistance between two corners is
(a) 8Ω (b) 12Ω
(c) 3/8 Ω (d) 8/3 Ω

53. Two wires of same metal have the same length but their cross-sections area in the ratio 3 : 1. They are joined in series. The resistance of the thicker wire is 10Ω. The total resistance of the combination will be
(a) 40 Ω (b) 40/3 Ω
(c) 5/2 Ω (d) 100 Ω

54. A certain piece of silver of given mass is to be made like a wire. Which of the following combination of length (L) and the area of cross-sectional (a) will lead to the smallest resistance
(a) L and A
(b) 2L and A/2
(c) L/2 and 2A
(d) Any of the above, because volume of silver remains same

55. A certain wire has a resistance R. The resistance of another wire identical with the first except having twice its diameter is
(a) 2R (b) 0.25 R
(c) 4R (d) 0.5 R

**56.** What length of the wire of specific resistance $48 \times 10^{-8}$ Ω-m is needed to make a resistance of 4.2 Ω (diameter of wire = 0.4 mm)

(a) 4.1 m (b) 3.1 m
(c) 2.1 m (d) 1.1 m

**57.** The resistance of an ideal voltmeter is

(a) zero (b) very low
(c) very large (d) Infinite

**58.** Masses of 3 wires of same metal are in the ratio 1 : 2 : 3 and their lengths are in the ratio 3 : 2 : 1. The electrical resistances are in ratio

(a) 1:4:9 (b) 9:4:1
(c) 1:2:3 (d) 27:6:1

**59.** When a 12Ω resistor is connected in series with a moving coil galvanometer then its deflection reduces from 50 divisions to 10 divisions. The resistance of the galvanometer is

(a) 24 ohm (b) 36 ohm
(c) 3 ohm (d) 60 ohm

**60.** In a Wheatstone's bridge all the four arms have equal resistance $R$. If the resistance of the galvanometer arm is also $R$, the equivalent resistance of the combination across the battery is

(a) $R/2$ (b) $R$
(c) $2R$ (d) $R/4$

**61.** We have two wires A and B of same mass and same material. The diameter of the wire A is half of that B. If the resistance of wire A is 24 ohm then the resistance of wire B will be

(a) 12 ohm (b) 3.0 ohm
(c) 1.5 ohm (d) None of the above

**62.** The electric resistance of a certain wire of iron is R. If its length and radius are both doubled, then

(a) The resistance will be doubled and the specific resistance will be halved
(b) The resistance will be halved and the specific resistance will remain unchanged
(c) The resistance will be halved and the specific resistance will be doubled
(d) The resistance and the specific resistance, will both remain unchanged

**63.** When a wire of uniform cross-section $a$, length $\ell$ and resistance $R$ is bent into a complete circle, resistance between any two of diametrically opposite points will be

(a) $R/4$ (b) $R/8$
(c) $4R$ (d) $R/2$

**64.** A solenoid is at potential difference 60V and current flows through it is 15 ampere, then the resistance of coil will be

(a) 4 Ω (b) 8 Ω
(c) 0.25 Ω (d) 2 Ω

**65.** The resistance of a discharge tube is

(a) Ohmic (b) Non-ohmic
(c) Both (a) and (b) (d) Zero

**66.** Conductivity increases in the order of

(a) Al, Ag, Cu (b) Al, Cu, Ag
(c) Cu, Al, Ag (d) Ag, Cu, Al

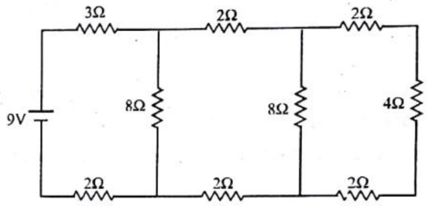
**67.** By increasing the temperature, the specific resistance of a conductor and a semiconductor

(a) Increases for both (b) Decreases for both
(c) Increases, decreases (d) Decreases, increases

**68.** A strip of copper and another of germanium are cooled from room temperature to 80 K. The resistance of

(a) Each of these increases
(b) Each of these decreases
(c) Copper strip increases and that of germanium decreases
(d) Copper strip decreases and that of germanium increases

**69.** In the circuit shown in the figure, the current through




(a) the 3Ω resistor is 0.50A
(b) the 3Ω resistor is 0.25A
(c) the 4Ω resistor is 0.50A
(d) the 4Ω resistor is 0.25A

**70.** Which of the following has a negative temperature coefficient?

(a) $C$ (b) $Fe$
(c) $Mn$ (d) $Ag$

## More than One Correct :

**DIRECTIONS :** *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONE OR MORE may be correct.*

**1.** A current passes through a wire of non-uniform cross-section. Which of the following quantities are independent of the cross-section?

(a) The charge crossing in a given time interval
(b) Drift speed
(c) Current density
(d) Free-electron density

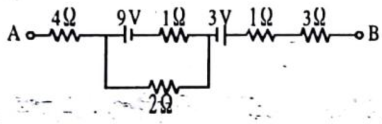
**2.** Two conductors made of the same material have lengths $L$ and $2L$, but have equal resistances. The two are connected in series in a circuit in which current is flowing. Which of the following is/are correct?

(a) The potential difference across the two conductors is the same
(b) The electron drift velocity is larger in the conductor of length $2L$
(c) The electric field in the first conductor is twice than that in the second
(d) The electric field in the second conductor is twice than that in the first

3. When a potential difference is applied across the ends of a linear-metallic conductor:
   (a) the free electrons are set in motion from their position of rest
   (b) the free electrons are accelerated continuously from the lower potential end to the higher potential end of the conductor
   (c) the free electrons are accelerated continuously from the higher potential end to the lower potential end of the conductor
   (d) the free electrons acquire a constant drift velocity from the lower potential end to the higher potential end of the conductor
   (e) the vibrating atomic ions in the conductor start vibrating more vigorously

4. Electric current arises from the flow of charged particles. Now:
   (a) in metals it is dominant due to flow of electrons
   (b) in semiconductors it is jointly due to flow of holes and electrons
   (c) in electrolytes it is due to flow of negative ions only
   (d) in discharge tubes containing gases at low pressure it is due to flow of positive ions only

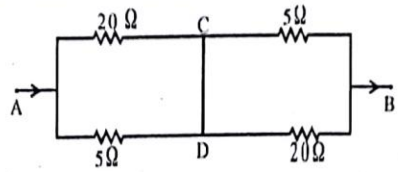
5. The potential difference between the points $A$ and $B$ in the circuit shown here is 16 volts. Then:




   (a) the current through the 2Ω resistance is 3.5 amp
   (b) the current through the 4Ω resistance is 2.5 amp
   (c) the current through the 3Ω resistance is 1.5 amp
   (d) the potential difference between the terminals of the 9V battery is 7V

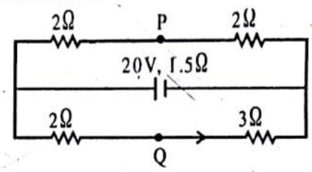
6. Electric current is due to flow of charge carriers in the conductors. Which of the following is/are correct?
   (a) The drift speed of charge carriers is a very small fraction of the mean thermal agitation speed of the same charge carriers
   (b) The number of charge carriers per unit volume is always the same as the number of atoms of the conductor per unit volume
   (c) The drift velocity is proportional to the electric field applled ordinarily
   (d) In an intrinsic semiconductor, the charge carriers are either electrons only or holes only; both of them may not participate in conduction

7. When some potential difference is maintained between $A$ and $B$, current $I$ enters the network at $A$ and leaves at $B$:



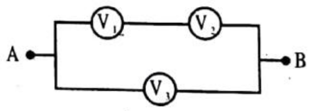

   (a) the equivalent resistance between $A$ and $B$ is 8Ω
   (b) $C$ and $D$ are at the same potential
   (c) no current flows between $C$ and $D$
   (d) current $(3I/5)$ flows from $D$ to $C$

8. In the given circuit:



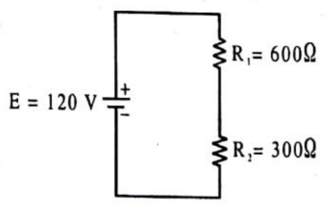

   (a) the current through the battery is 5.0 amp
   (b) $P$ and $Q$ are at the same potential
   (c) $P$ is 2.5 V higher than $Q$
   (d) $Q$ is 2.5 V higher than $P$

9. Three voltmeters, all having different resistances, are joined as shown in the figure. When some potential difference is applied across $A$ and $B$, their readings are $V_1$, $V_2$, $V_3$:



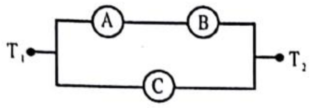

   (a) $V_1 = V_2$   (b) $V_1 \neq V_2$
   (c) $V_1 + V_2 = V_3$   (d) $V_1 + V_2 > V_3$

10. In the circuit, the battery is ideal. A voltmeter of resistance 600 Ω is connected in turn across $R_1$ and $R_2$, giving readings $V_1$ and $V_2$ respectively:




   (a) $V_1 = 80$ V   (b) $V_1 = 60$V
   (c) $V_2 = 30$ V   (d) $V_2 = 40$ V

**11.** Three ammeters $A$, $B$ and $C$ of resistances $R_A$, $R_B$ and $R_C$ respectively are joined as shown in the figure. When some potential difference is applied across the terminals $T_1$ and $T_2$, their readings are $I_A$, $I_B$ and $I_C$ respectively:




(a) $I_A = I_B$
(b) $I_AR_A + I_BR_B = I_CR_C$
(c) $\frac{I_A}{I_C} = \frac{R_C}{R_A}$
(d) $\frac{I_B}{I_C} = \frac{R_C}{R_A + R_B}$

## FIP Fill in the Passage :

**DIRECTIONS :** *Complete the following passage(s) with an appropriate word/term to be filled in the blank spaces.*

**I.**

| | | | |
|---|---|---|---|
| resistance | conductor | free electrons | high potential |
| low potential | positive ions | obstructions | |

Conductors conduct electricity owing to the presence of a large number of ...... 1...... .When a potential difference is applied across a conductor these electrons begin to drift from the end at ...... 2....... to the end at ...... 3....... While drifting they collide with other electrons as well as fixed ...... 4....... . The fixed ions are formed from the atoms which given free electrons. Thus, even as conductor conducts electricity, at the same time it offers some ...... 5....... to the flow of charges.

The obstruction offered by a ...... 6....... to the flow of electric current is called its ...... 7....... .

**II.**

| | | | |
|---|---|---|---|
| flowing | amount | unit time | surface |
| conductor | directly | potential difference. | |

The electric current is defined as the .......1........ of charge for .......2........ that crosses the .......3........, in much the same sense that a river current is the amount of water .......4........ per unit time.When physical conditions remaining same, then the electric current flowing through a .........5........... is .........6...... proportional to the .........7........... across the two ends of the conductor.

**III.**

| | | | |
|---|---|---|---|
| Starting point | end point | sum difference | individual |
| $R_1 - R_2$ | $R_1 + R_2$ | resistances | potential difference |
| series. | | | |

In a series combination of resistors, the ........1........ of one resistor is connected to the ........2........ of second resistor. Then the effective resistance of the combination is equal to the ........3........ of the resistances of ........4........ resistors.

If $R_1$ and $R_2$ are the resistances of two resistors connected in series combination, their effective or net resistance is given by $R_{net}$ = ........5........ This is true for '**n**' number of resistors connected in series combination. Thus, we have $R_{net} = R_1 + R_2 + R_3$ ........... $R_n$, where $R_1, R_2, R_3 +$ ..........., $R_n$ are the resistances of 'n' resistors connected in ........6........ arrangement.

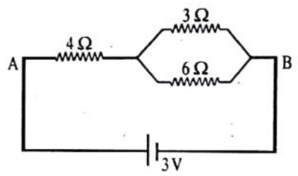
Thus, the net resistance of the combination obtained is greater than the largest value of resistance in the combination. In this type of combination, the potential difference across the combination of resistors is divided among the resistors according to the values of their ........7........ Hence, the resistors in this type of combination act as dividers of ........8........ .

## PBQ Passage Based Questions :

**DIRECTIONS :** *Study the given paragraph(s) and answer the following questions.*

**Passage -I**

Answer the following questions based on the given circuit.



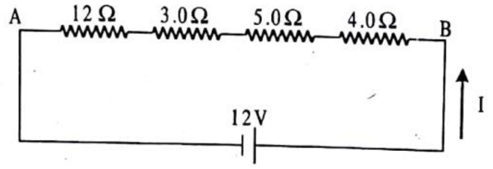

**1.** The potential drop across the 3Ω resistor is
(a) 1V (b) 1.5V
(c) 2V (d) 3V

**2.** The equivalent between points A and B is
(a) 7Ω (b) 6Ω
(c) 13Ω (d) 5Ω

**3.** The current flowing through in the given circuit is
(a) 0.5 A (b) 1.5 A
(c) 6 A (d) 3 A

**Passage -II**

Answer the following questions based on the given circuit.

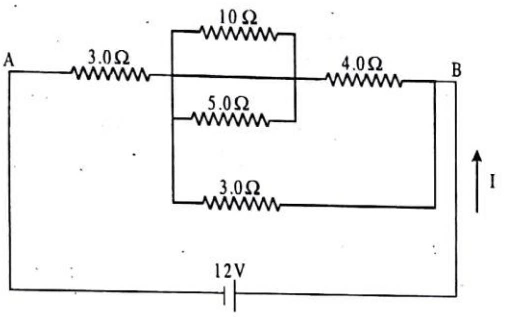



**1.** The equivalent resistance between points A and B, is
(a) 12 Ω (b) 36 Ω
(c) 32 Ω (d) 24 Ω

2. The current through each resistor is
   (a) 1 A (b) 2.3 A
   (c) 0.5 A (d) 0.75 A
3. The potential drop across the 12Ω resistor is
   (a) 12 V (b) 6 V
   (c) 8 V (d) 0.5 V

**Passage -III**

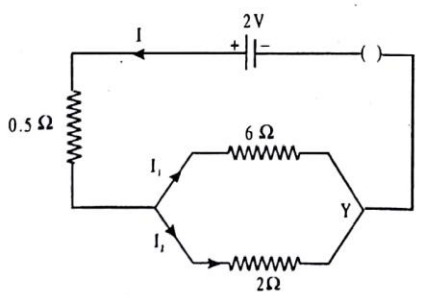
Answer the following questions based on the given circuit.




1. The equivalent resistance between points A and B
   (a) 6.2 Ω (b) 5.1 Ω
   (c) 13.33 Ω (d) 1.33 Ω
2. The current through the battery is
   (a) 2.33 A (b) 3.12 A
   (c) 4.16 A (d) 5.19 A
3. The current through the 4.0 ohm resistor is
   (a) 5.6 A (b) 0.98 A
   (c) 0.35 A (d) 0.68 A

**Passage -IV**

Answer the following questions based on the given circuit.



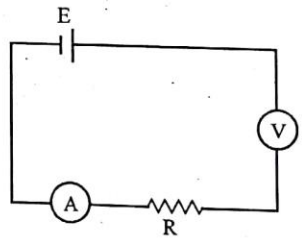

1. The total resistance of the circuit is
   (a) 2 Ω (b) 4 Ω
   (c) 1.5 Ω (d) 0.5 Ω
2. The current flowing through 0.5Ω resistor is
   (a) 1 A (b) 1.5 A
   (c) 3 A (d) 2.5 A
3. The current flowing through 6Ω resistor is
   (a) 0.50 A (b) 0.75 A
   (c) 0.80 A (d) 0.25 A

## A&R Assertion & Reason :

**DIRECTIONS :** *Each of these questions contains an Assertion followed by reason. Read them carefully and answer the question on the basis of following options. You have to select the one that best describes the two statements.*

(a) If both **Assertion** and **Reason** are **correct** and Reason is the **correct explanation** of Assertion.
(b) If both **Assertion** and **Reason** are correct, but Reason is **not the correct explanation** of Assertion.
(c) If **Assertion** is **correct** but **Reason** is **incorrect**.
(d) If **Assertion** is **incorrect** but **Reason** is **correct**.

1. **Assertion :** When a battery is short-circuited, the terminal voltage is zero.
   **Reason :** In the situation of a short-circuit, the current is zero
2. **Assertion :** The equation $V = Ri$ does not apply to those conducting devices which do not obey Ohm's law.
   **Reason :** $V = Ri$ is a statement of Ohm's law.
3. **Assertion :** All electric devices shown in the circuit are ideal: The reading of each of ammeter (a) and voltmeter (V) is zero.




   **Reason :** An ideal voltmeter draws almost no current due to very large resistance, and hence (V) and (a) will read zero.
4. **Assertion :** If $\rho_1$ and $\rho_2$ be the resistivities of the materials of two resistors of resistances $R_1$ and $R_2$ respectively and $R_1 > R_2$, then $\rho_1 > \rho_2$.
   **Reason :** The resistance $R = \rho \frac{\ell}{A} \Rightarrow \rho_1 > \rho_2$ if $R_1 > R_2$
5. **Assertion :** The product of resistivity and conductivity of a conductor depends on the material of the conductor.
   **Reason :** Because each of resistivity and conductivity depends on the material of the conductor.
6. **Assertion :** Insulators do not allow flow of current through themselves.
   **Reason :** They have no free-charge carriers.

7. **Assertion :** Positive charge inside the cell always goes from positive terminal to the negative terminal.
**Reason :** Positive charge inside the cell may go from negative terminal to the positive terminal.

8. **Assertion :** Wire A is thin in comparison to wire B of same material same length then resistance of wire A is greater than resistance of wire B.
**Reason :** Resistivity of wire A is greater than resistance of wire B.

9. **Assertion :** Resistivity of material may change with temperature.
**Reason :** Resistivity is a material property & independent on temperature.

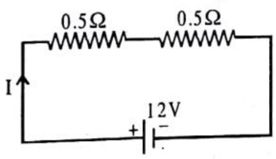
## MMQ Multiple Matching Questions :

**DIRECTIONS :** *Following question has four statements (A, B, C and D) given in Column I and four statements (p, q, r and s) in Column II. Any given statement in Column I can have correct matching with one or more statement(s) given in Column II. Match the entries in column I with entries in column II.*

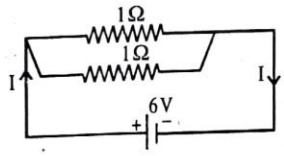
1.

| Column I | Column II |
|---|---|
| (A) Ohm's Law | (p) Direct proportional to area |
| (B) Resistivity | (q) Voltage α current |
| (C) For Ohmic-conductor | (r) $\frac{\text{charge}}{\text{time}}$ |
| (D) Electric current | (s) $V = IR$ |

2. **Column I** — **Column II**

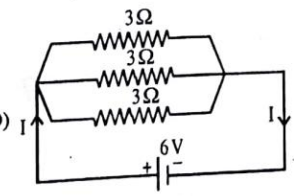
(A) 


(p) $R_{eq} = 1\Omega, I = 12A$

(B) 


(q) α Length

(C) Resistance — (r) $R_{eq} = 1\Omega, I = 6A$

(D) 

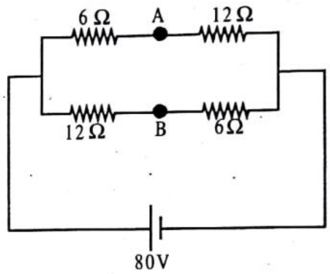

(s) $\alpha \frac{1}{\text{Area}}$

3.

| Column I | Column II |
|---|---|
| (A) Ohm | (p) 1 Volt / 1 Amp |
| (B) Current | (q) Depends on matter of conductor |
| (C) Resistivity | (r) $\frac{\text{charge}}{\text{time}}$ |
| (D) Super conductor | (s) $\frac{\text{Resistance}}{\text{Zero}}$ |

## HOTS Subjective Questions :

1. In the circuit shown, if a wire is connected between points A and B. How much current will flow through that wire?




2. A potential difference V is applied across a conductor of length L and diameter D. How the electric field E and resistance R effected when
(i) V is halved (ii) L is halved
(iii) D is doubled
Justify your answer in each case.
3. What is the number of electrons that would flow per second through the cross-section of a wire when 1 A current flows in it?
4. 0.7C charge passes through a cross-section of a conductor in 7 s. Find the current.
5. A current of 1.2 A flows through a conductor for 3.0 s. What amount of charge passes through the conductor?
6. Name a metal which offers higher resistance to the passage of electricity other than copper.
7. Define the term resistivity of a material.
8. Calculate the resistance of a conductor, if the current flowing through it is 0.2 A when the applied potential difference is 0.8 volt.
9. A cylinder of a material is 10 cm long and has a cross-section of $2cm^2$. If its resistance along the length be 20Ω, what will its resistivity value be in number and units?
10. Two wires, one of manganin and the other of copper have equal lengths and resistances. Which one of these wires will be thicker?
11. A student obtains resistances 3,4,12 and 16Ω using only two metallic resistance wires are either separately or joined together. What is the value of resistance of each of these wires?

# SOLUTIONS

Brief Explanations of Selected Questions

## Exercise 1

### FILL IN THE BLANKS :

1. Green, red, black
2. current
3. ammeter
4. zero
5. potential difference
6. series
7. potential difference
8. resistivity
9. ampere
10. Resistance
11. ohm ($\Omega$)
12. directly proportional, temperature
13. length, area of cross-section, material
14. resistance
15. low
16. ammeter
17. superconductivity

### TRUE / FALSE

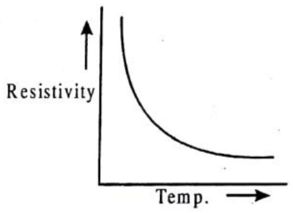
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1. | True | 2. | True | 3. | False | 4. | True |
| 5. | False | 6. | False | 7. | True | 8. | False |
| 9. | True | 10. | True | 11. | True | 12. | True |
| 13. | False | 14. | False | 15. | False | | |

### MATCH THE FOLLOWING :

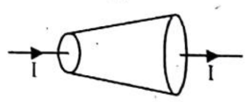
1. (a) $\rightarrow$ q; (b) $\rightarrow$ p; (c) $\rightarrow$ s; (d) $\rightarrow$ r
2. (a) $\rightarrow$ q;, (b) $\rightarrow$ p; (c) $\rightarrow$ r; (d) $\rightarrow$ s
3. (a) $\rightarrow$ q; (b) $\rightarrow$ r; (c) $\rightarrow$ p; (d) $\rightarrow$ q

### VERY SHORT ANSWER QUESTIONS :

5. Ammeter
6. Ohm.
7. Silver
8. No, various distribution circuits are connected in parallel.
9. If an ammeter is connected in parallel, the resultant resistance of the circuit decreases and more current passes through the instrument. Hence, the ammeter is likely to be burnt out.
10. It is very-very large, say almost infinity.
11. Manganin is an alloy whose temperature coefficient of resistance is almost negligible. So its resistance does not change with change in temperature, that is why it is used in making standard resistors.
12. Resistivity will not change as it depends on the material not on the length.
13. Resistivity will not change as it depends on the material not on the diamater of the wire.
14. Voltage is measured across any two points of a conductor by a voltmeter connected in parallel because potential difference across parallel combination of elements remains same.
15. Slope of voltage vs. current graph gives resistance of a metallic conductor. S.I. unit is ohm.
16. $74\ k\Omega = 74 \times 10^3\ \Omega$. Violet, yellow and orange.
17. The specific resistance of silver is least. So it is the best conductor as the conductivity is the reciprocal of specific resistance.
18.




19. A current carrying wire consists of equal number of electrons and protons. Therefore, the wire is not electrically charged.
20. $I = qnAv_d \Rightarrow v_d \propto \frac{1}{A}$




i.e, as the area of cross-section of wire increases in the direction of current I, the drift speed of charge carriers decreases in that direction.

21. Resistance increases with increase in temperature. Resistance of metallic wire is the inverse of slope of the graph $R$ is more at $T_2 \therefore T_2 > T_1$.
22. If both voltage and resistance are doubled, there will be no change in the current.
23. Dry skin has greater resistance than wet skin. There is usually a layer of salt remaining on our skin from respiration. When the skin is wet the salt lowers its resistance.
24. The source of electrons that makes a shock when we touch a charged conductor is our body itself.
25. Red – 2, Black – 0, Orange – 3, Silver – $\pm$ 10% = tolerance

### SHORT ANSWER QUESTIONS :

5. $I = 0.5\ A,\ V = 230$ volt

$$R = \frac{V}{I} = \frac{230}{0.5} = 460\ \Omega$$

6. Two resistance in parallel, and the third in series with them.

7. (a) When a number of resistances are connected in parallel then their combined resistance is less than the smallest individual resistance. Therefore, equivalent resistance will be less than 1.

(b) In this case, also the equivalent resistance will be less than 1.

8. We are given the resistance R of the wire $= 26\Omega$, the diameter $d = 0.3$ mm $= 3\times10^{-4}$ m and the length $\ell$ of the wire $= 1m$

We know that the resistivity of the given metallic wire is

$$\rho = \left(\frac{RA}{\ell}\right) = \left(\frac{R\pi d^2}{4\ell}\right)$$

$$= \frac{26\times22\times3\times10^{-4}\times3\times10^{-4}}{7\times4\times1} = 183.857\times10^{-8}$$

$= 1.84\times10^{-8}\,\Omega$m

The resistivity of the metal at 20°C is $1.84\times10^{-8}\,\Omega$m

9. Equivalent resistance of circuit $R = 4\Omega$.

Equivalent resistance of $2\Omega$ and $x$ in series

$R_1 = 2\Omega + x$ .......... (a)

Equivalent resistance of $7\Omega$ and $5\Omega$ in series

$R_2 = 7 + 5 = 12\Omega$.

As $R_1$ and $R_2$ are in parallel

$$\therefore \frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} \Rightarrow \frac{1}{4} = \frac{1}{R_1} + \frac{1}{12}$$

$$\therefore \frac{1}{R_1} = \frac{1}{4} - \frac{1}{12} = \frac{2}{12} = \frac{1}{6}$$

Putting value of $R_1$ in (a)

$6 = 2 + x$ $\quad\therefore x = 6 - 2 = 4\,\Omega$.

10. For higher current there are higher heat or energy losses as

$V = I^2 R$

11. $I = qnAv_d \Rightarrow \frac{V}{R} = qnAv_d \Rightarrow \frac{VA}{\rho l} = qnAv_d \Rightarrow v_d = \frac{V}{\rho lqn}$

i.e., the drift speed of charge carriers does not depend on the diameter of wire.

12. In conductors, one or more electrons from each atom are free to move throughout the atomic lattice. The movement of electrons produce electric current in the conductor. Protons, on the other hand, are bound to the nuclei of atoms that are more or less locked in a fixed positions. Therefore, protons can't move and hence can't contribute to the current.

13. Electric charges flow through a circuit just like the molecules of water flow through a pipe if there is a pressure difference between its ends.

On the other hand, voltage doesn't flow across a circuit but it is just impressed across a circuit. Voltage doesn't go anywhere in a circuit just like pressure doesn't go through the pipe in the example above.

14. $10\Omega$

15. $6\Omega$

## LONG ANSWER QUESTIONS :

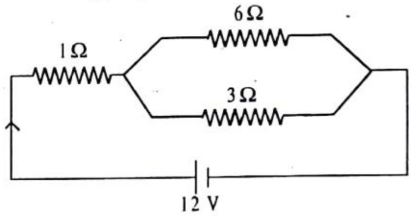
2. Effective resistance in the parallel circuit is

$$\therefore \frac{1}{R_1} = \frac{1}{6} + \frac{1}{3} = \frac{1+2}{6} = \frac{3}{6} = \frac{1}{2}$$

$\Rightarrow R_1 = 2\,\Omega$

Total resistances $R = 1 + 2 = 3\Omega$

Current $I = \frac{V}{R} = \frac{12}{3} = 4A$

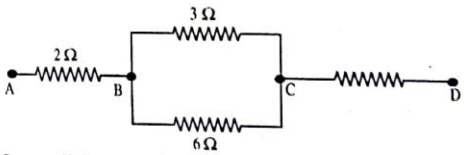



3. 122.7 $m$, 1/4 minutes.

4. 1.5 ampere, 30 volts, 45 volts.

5. (i) $0.4\,\Omega m^{-1}$ (ii) $0.8\,\Omega$ (iii) 1

6. (a) As the total resistance (equivalent resistance) is $4\Omega$, the $6\Omega$ resistor cannot be in series. So, it must be in parallel with some other resisters.




In parallel connection, the equivalent resistance ($4\Omega$) has to be less than all the resistances. So, the resistors of $2\Omega$ and $3\Omega$ cannot be in parallel at one time with $6\Omega$.

So, the resistors have to be in a mixed combination. Let us consider the combination show in the figure.

The equivalent resistance between $B$ and $C$ (which are in parallel) $= \frac{3\Omega\times6\Omega}{3\Omega+6\Omega} = \frac{18\Omega}{9\Omega} = 2\Omega$

The resistance between $A$ and $D = 2\Omega + 2\Omega = 4\Omega$.

So, the combination shown in the figure is true.

7. Resistors are connected in series.

So, equivalent resistance

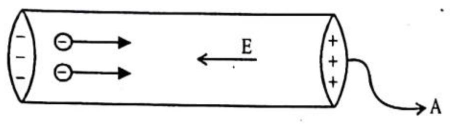
$R = 0.2\,\Omega + 0.3\,\Omega + 0.4\,\Omega + 0.5\,\Omega + 12\,\Omega = 13.4\,\Omega$.

Potential difference, $V = 9V$

Current, through the circuit, $I = \frac{V}{R} = \frac{9}{13.4} = 0.67\,A$

8. Drift velocity is defined as the average velocity with which the free electrons get drifted towards the positive end of the conductor under the influence of an external electric field.

Relaxation time is the average time that has elapsed since each electron suffered its last collision with the atoms or ions of conductor.




Consider a metalic conductor of length $l$, and $V$ be the potential difference applied across the ends. Then the magnitude of electric field, $E = \frac{V}{\ell}$.

Since the charge on electron is $-e$, each electron experiences a force, $\vec{F} = -e\vec{E}$ .......(i)

If $m$ is the mass of an electric, the acceleration of each electron is, $\vec{a} = \frac{-e\vec{E}}{m}$ ........(ii)

Due to this acceleration, apart from its thermal velocity, acquires additional velocity component in a direction opposite to the direction of electric field. At any instant of time, the velocity acquired by electron having thermal velocity $u_1$ will be $\vec{v}_1 = \vec{u}_1 + \vec{a}\tau_1$ and so on.

Where $\tau_1$ is the time elapsed after it's last collision.

$\therefore$ The average velocity of all the electrons in the conductor (i.e., the drift velocity)

$$\vec{v}_d = \frac{\vec{v}_1 + \vec{v}_2 + \ldots + \vec{v}_n}{n} = \frac{\vec{a}(\tau_1 + \tau_2 + \ldots + \tau_n)}{n}$$ (Since the average thermal velocity of electrons is zero).

$= \vec{a}\tau$ where $\tau = \frac{\tau_1 + \tau_2 + \ldots + \tau_n}{n}$ is the relaxation time.

Putting the value of $\vec{a}$ from (2) drift velocity speed

$$\vec{v}_d = \frac{e\vec{E}\tau}{m}.$$

$\therefore$ Average drift speed $v_d = \frac{eE\tau}{m}$

**9.** The resistivity of the material of a conductor is defined as the resistance of unit length and unit area of cross–section of the conductor. The S.I. unit of resistivity is ohm metre ($\Omega m$).

Resistivity of a material,

$\rho = \frac{m}{ne^2\tau}$ or $\rho \alpha \frac{1}{n\tau}$ Where $m$ is the mass of electron, $n$ is the number density of electron and $\tau$ is the average relaxation time. This shows that the resistivity is related to two parameters of the material namely $n$ and $\tau$.

The variation of resistivity with temperature is different in different materials.

(a) **For metallic conductors**

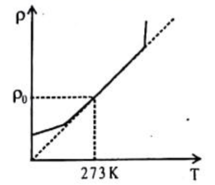
The temperature dependence of resistivity of a metal is given by the relation,

$$\rho = \rho_0[1 + \alpha(T - T_0)] \quad \ldots\ldots\ldots\ldots(1)$$

Where $\rho$ and $\rho_0$ are the resistivity at temperature T and $T_0$ respectively and $\alpha$ is called temperature coefficient of resistivity.

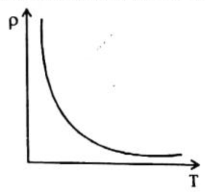
$$\therefore \quad \alpha = \frac{\rho - \rho_0}{\rho_0(T - T_0)} = \frac{d\rho}{\rho_0}.\frac{1}{dT} \quad \ldots\ldots\ldots\ldots(2)$$

The resistivity of a conductor increases with increase in temperature since $\alpha$ is positive. The variation of resistivity of copper with temperature is as shown.




(b) **For Semiconductors**

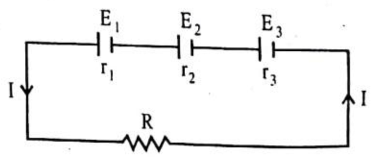
For Semiconductors, the resistivity decreases as temperature increases since the value of $\alpha$ is negative.




(c) **For insulators**

The resistivity increases exponentially with decrease in temperature. It becomes infinitely large at temperatures near absolute zero.

**10.** (a) **When cells are arranged in series**




Consider three cells of e.m.f $E_1$, $E_2$, $E_3$ of internal resistances $r_1$, $r_2$, $r_3$ are connected in series through an external resistor $R$. The same current $I$ flows through the cells.

The equivalent internal resistance of this combination is $r_{eq} = r_1 + r_2 + r_3$.

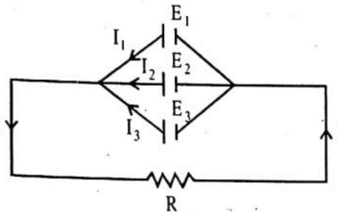
If $n$ cells each of e.m.f $E$ and internal resistance $r$ are connected to the external resistor $R$, then, the equivalent e.m.f of this combination, $E_{eq} = nE$.

Equivalent internal resistance of $n$ cells in series $r_{eq} = nr$.

$\therefore$ Total resistance of the circuit = $nr + R$.

$\therefore$ Current in the circuit $I = \frac{nE}{nr+R}$.

(b) **When cells are arranged in parallel**




In this combination of cells, the total current is the sum of the currents due to individual cells. Total emf of this combination is the same ($E$).

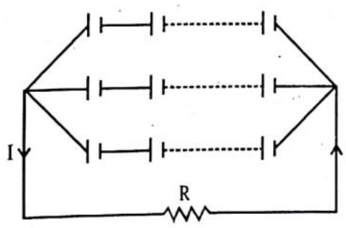
The equivalent internal resistance $\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3}$

If $m$ cells are connected in parallel, each of emf $E$ and internal resistance $r$ to the external resistor $R$, then the current,

$$I = \frac{E}{R + r/m} = \frac{mE}{mR + r}$$

(c) **When the cells are in mixed grouping**

If there be $n$ cells in series in one row and $m$ rows of cells in parallel. Suppose the cells are identical with each cell be of e.m.f. $E$ and internal resistance $r$.




Total resistance in the circuit = $\frac{R+nr}{m}$

Total emf of all the cells = $nE$

$\therefore$ Current in the external resistance $R$ is

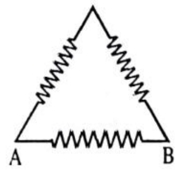
$$I = \frac{nE}{R + \frac{nr}{m}} = \frac{mnE}{mR + nr}$$

## Exercise 2

**MULTIPLE CHOICE QUESTIONS :**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **1.** | (c) | **2.** | (c) | **3.** | (b) | **4.** | (d) | **5.** | (c) |
| **6.** | (b) | **7.** | (d) | **8.** | (c) | **9.** | (b) | **10.** | (d) |
| **11.** | (b) | **12.** | (d) | **13.** | (b) | **14.** | (c) | **15.** | (c) |
| **16.** | (a) | **17.** | (d) | **18.** | (c) | **19.** | (c) | **20.** | (d) |
| **21.** | (a) | **22.** | (c) | **23.** | (a) | **24.** | (b) | **25.** | (b) |
| **26.** | (c) | **27.** | (a) | **28.** | (b) | **29.** | (d) | **30.** | (c) |
| **31.** | (c) | **32.** | (b) | **33.** | (d) | **34.** | (a) | **35.** | (a) |
| **36.** | (a) | **37.** | (a) | **38.** | (b) | **39.** | (d) | **40.** | (b) |
| **41.** | (d) | **42.** | (b) | **43.** | (d) | **44.** | (b) | **45.** | (d) |
| **46.** | (c) | **47.** | (b) | **48.** | (b) | **49.** | (b) | **50.** | (c) |
| **51.** | (b) | | | | | | | | |

**52.** (d) $R_{AB} = \frac{(4+4)\times 4}{4+4+4} = \frac{8}{3}\Omega$




**53.** (a) Same metal means same sp. resistance

$$\frac{R_1}{R_2} = \frac{A_2}{A_1} = \frac{1}{3} \Rightarrow R_2 = 3R_1 = 3\times 10 = 30\Omega$$

$$R = R_1 + R_2 = 40\Omega$$

**54.** (c) $R \propto \frac{\ell}{A}$. Hence minimum for option (c)

**55.** (b) $R \propto \frac{1}{A} \propto \frac{1}{r^2}$. Hence $\frac{1}{4}^{\text{th}}$

**56.** (d) $R = \frac{\rho\ell}{A}$ ; $\ell = \frac{RA}{\rho} = \frac{4.2\times\pi\left(\frac{0.4}{2}\times 10^{-3}\right)^2}{4.8\times 10^{-8}} = 1.1m$

**57.** (c) Ideal voltmeter should not draw any current flow source hence its resistance = $\infty$.
Practically $\infty$ resistance is not possible, but ideal voltmeter is possible with the help of potentiometer that you will learn in higher classes.

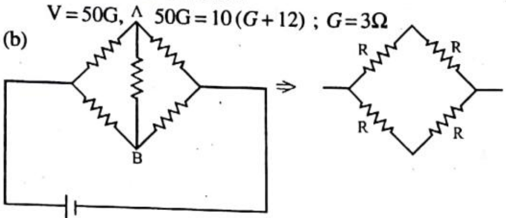
**58.** (d) $R = \frac{\rho\ell}{A} = \frac{d\rho\ell^2}{m}$ ; $R \propto \frac{\ell^2}{m}$

$$\left[V = A\ell, d = \frac{m}{v} = \frac{m}{A\ell} \Rightarrow A = \frac{m}{d\ell}\right]$$

$$R_1 : R_2 : R_3 \equiv \frac{9}{1} : \frac{4}{2} : \frac{1}{3} \equiv 9 : 2 : \frac{1}{3} = 27 : 6 : 1$$

**59.** (c) $i \propto$ division deflected.
$V = 50G$, $\wedge$ $50G = 10(G+12)$ ; $G = 3\Omega$

**60.** (b)




As Wheatstone bridge is in balanced condition potential difference across $AB$ is zero hence resistance across $AB$ is ineffective circuit reduce to simple circuit as shown resistance $R$ in upper branch are in series and in parallel with lower branch.
$R_{eq} = R.$

**61.** (c) Same material $\rightarrow$ same density, specific resistance as they are material property.

$$R = \frac{\rho \ell}{A} = \frac{\rho V}{A^2} = \frac{\rho m}{dA^2}$$

$$R \propto \frac{1}{A^2} \propto \frac{1}{r^4}$$

$$\frac{R_A}{R_B} = \frac{r_B^4}{r_A^4} = 2^4 = 16 \Rightarrow R_B = \frac{24}{16} = 1.5\,\Omega$$

**62.** (b) $R = \dfrac{\rho \ell}{A} = \dfrac{\rho \ell}{\pi r^2}$

$$R' = \frac{\rho 2\ell}{\pi (2r)^2} = \frac{R}{4}$$

Specific resistance will remain same as it is a material property but remember it depends on temperature.

**63.** (a) Two resistance ($R/2$) will be in parallel, hence
$R_{eq} = R/4$

**64.** (a) $V = i \times R$ ; $R = 60/15 = 4\,\Omega$

**65.** (b)

**66.** (b) Silver is the best conductor of electricity.

**67.** (c)

**68.** (d) Copper is a conductor while germanium is a semi-conductor. Resistance of temperature decreases with temperature while that of semi-conductor increases hence resistance of copper strip decreases and that of germanium increases.

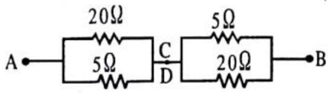
**69.** (d) $2\Omega, 4\Omega, 2\Omega$ on right side are in series resultant parallel to $8\Omega$ then in series with $2\Omega$, $2\Omega$ then in parallel with $8\Omega$, then in series with $3\Omega, 2\Omega$. Thus, $R_{eq} = 9$ ohm.
$i = 9/9 = 1$ amp flow from battery.
Passing through $3\Omega$ it will divide into equal parts (1/2 amp) in $8\Omega$ (near to cell) and remaining section then again divide into equal parts (1/4 amp) in $8\Omega$ (middle one) and remaining section hence 1/4 amp. passes through $4\Omega$.

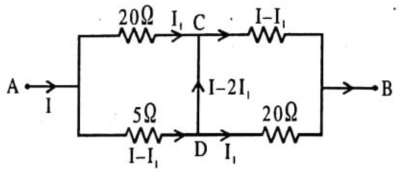
**70.** (a)

## MORE THAN ONE CORRECT :

**1.** (a, d) **2.** (a, b, c) **3.** (d, e)
**4.** (a, d) **5.** (a, c, d) **6.** (a, c)

**7.** (a,b,d)




As $C$ and $D$ are joined, they must be at the same potential, and may be treated as the same point. This gives the equivalent resistance as $8\Omega$. If we distribute current in the network, using symmetry

$$V_A - V_D = V_A - V_C$$

or $20I_1 = 5(I - I_1)$ or $I_1 = \dfrac{I}{5}$

$\therefore$ $I - 2I_1 = 1 - \dfrac{2I}{5} = \dfrac{3I}{5}$

= Current flowing from $D$ to $C$

**8.** (a, d)

**9.** (b, c)

**10.** (b, c) Treat all voltmeters and ammeters as resistances. Draw the circuit and find the currents and potential differences for each section.

**11.** (a, b, d)

## FILL IN THE PASSAGE :

**I.** 1. free electrons 2. low potential 3. high potential 4. positive ions 5. obstructions 6. conductor 7. resistance

**II.** 1. amount 2. unit time 3. surface 4. flowing 5. conductor, 6. directly 7. potential difference.

**III.** 1. end point, 2. starting point, 3. sum difference, 4. individual 5. $R_1 - R_2, R_1 + R_2$, 6. series 7. resistances 8. potential difference,

## PASSAGE BASED QUESTIONS :

Passage: I

**1.** (a) Equivalent resistance of $3\Omega$ and $6\Omega$ = $\dfrac{3 \times 6}{3+6} = 2\Omega$

as they are in parallel they have same p.d.

$$i = \frac{3}{6} = \frac{1}{2}$$

P.D. across $2\Omega = \dfrac{1}{2} \times 2 = 1$ volt